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THESIS

THE CHEMISTRY OF WARFARE - A MOTIVATING UNIT

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CHAPTER I INTRODUCTION

When headlines are screaming war news and the front page stories are filled with tales of battles, air-raids, and the sinking of ships, why should we think of chemists? They seem a quiet lot and not at all the stuff of which news is made today.

However, but for certain of these men of science battles would still be fought with muskets and cast-iron cannon; there wouldn't be any such thing as a bomber, no ship would be sunk by an electro-magnetic mine, and there would be no "eggs" filled with thermite to set cities aflame.

Yes, but for the chemist - a lover of peace - war would hold few of its present terrors. That seems a paradox until we realize that most of the weapons of destruction, devised by chemical means, were originally developed for purposes purely pacific and later conscripted to further warlike ends.

Take the chemical formulae for making the steels that make the guns, and the alloys that go into the metal fighting planes: neither steels nor alloys were devised primarily for the fabrication of engines of death.

And the octane fuels which have added tremendously to the death-dealing capacity of bombers were developed by chemistry to increase the payload of the useful commercial plane.

As for high explosives, they were nearly all discovered in the course of experiments connected with the dye industry, but their innocuous birth makes them no less deadly. Moreover pyrotechnics, which are so valuable for military signalling,

were originally introduced as fireworks, for display purposes.

Even some of the toxic gases were first prepared by men who never dreamed of their ultimate and sinister destiny. Phosgene and mustard gas, which took the heaviest toll of English lives in the last war - and which are most feared in Britain today - were discovered by Englishmen who merely noted their physiological properties as interesting data.

When these and other lethal substances were used by their enemies, then English (and French) chemists set about discovering ways of protecting their soldiers against the deadly fumes, and gas masks came into being. Combat gases of greater and greater potency were devised - as well as more effective means of producing them.

Such combat gases have now been developed to such a point that today civilians as well as soldiers are faced with the possibility of being sprayed or sprinkled with liquids, a few drops of which may prove fatal. And it is up to the chemists to provide protective clothing and masks, and to know how to decontaminate areas which have been infected.

It is their job, too, to supply the drugs and medicines which ease the pains of the wounded and restore the sick to health. And chemists are responsible for the disinfectants which destroy the germs which lurk in camps and trenches, just as it is chemists who prepare the vitamin pills which help men combat the germs they cannot escape.

In the last war chemistry was injected bodily into the holocaust and from that time on was to be more and more closely

connected with warfare.

Today national defense has become a matter of vital importance, as well as a topic of prime interest to the entire country. Everyone, young and old is aware of the placement of huge war orders, the virtual conversion of factories into war plants, and the staggering increase in the production of armaments. Selective service is now an actuality. Every high-school youth must look forward to the possibility of spending a year familiarizing himself with the implements of warfare. Every high-school girl must expect to see one of her family or friends inducted into service. In the event of war she must expect to learn the fundamentals of nursing and first aid, and, if necessary, be ready to work in the war plants themselves.

At a time like this the chemistry of warfare, tempered at the same time by a study of the peacetime uses of the same chemicals, should be an important factor in motivating a course in high school chemistry.

Motivation need not be a matter of accident; it can be consciously and carefully planned. Students of motivation recognize it as a technique, which means that it can be accomplished by known procedures. Work is motivated for a child:

(1) If he sees its uses and application

(2) If it connects with his present interests.

(3) If he develops a feeling of need.

(4) If the feeling of need leads to desire and choice.

(5) If human appeals are developed.[1]

The war and the many chemical happenings will make it easy to connect chemistry with the child's present interests. This will be the start. Gradually, with a skillful teacher, all of the above five points will be operating to urge the child forward, Motivation means that the child is thoroughly and fundamentally interested, interested to the extent that the compelling power for further work comes from within. Motivation is a first step in all good teaching.

But while the initial interest in chemistry may come from its part in a war that already affects us, and into which we are surely going to be involved, the further work of the student need not relate to warfare. However some few students may want to study the chemistry that first secured their interests. Therefore, there is developed in chapters III-VIII the essential background chemistry of warfare, which the prepared teacher may skillfully use as he develops chemical laws and techniques, and into which he will lead a few pupils to go much further.

1. Wilson, G. M., Teaching Levels, Teaching Technique, and the Project, p. 325.

CHAPTER II METHOD OF STUDY

The thesis deals with the part chemistry plays in the various components of modern warfare. It takes up in sequence (1) explosives, projectiles, and fuses; (2) the composition of pyrotechnics, how they function, and the colors they produce; (3) the physical and chemical nature of gases, smokes, and incendiaries, their tactical use, weapons, and the method of defense against chemical attack; (4) the soldier and his dependence on chemistry; (5) the armaments; and (6) the all-important relation of chemical industry to chemical warfare.

While it would be possible to outline a complete high-school chemistry course, using as a basis for study the chemical necessary for warfare, the thesis rather attempts to present a sample of the wealth of material in one important phase of chemistry, from which a chemistry teacher properly prepared can choose illustrative materials knowing that such illustrations will be charged with motivation.

Nevertheless, in order to direct a teacher of chemistry who might read this thesis, to the possibility of specific plans for using it, a chapter has been added (see chapter IX), which gives definite suggestions for use at the high school level.

CHAPTER III MUNITIONS

A. Explosives

The development during the World War of the methods of warfare termed "Chemical Warfare" created for the chemist unlimited opportunities for the exercise of his talents in producing toxic and lachrymatory gases, smokes of various types, incendiaries, and reliable means of protection against such materials. Since the fourteenth century, however, all warfare between civilized nations has been essentially "Chemical Warfare". The utilization of black powder for propelling missiles from cannon and rifles made the chemical industry a vital factor in warfare, and the later development of smokeless powders and of high explosives suitable for use as bursting charges still further emphasized the importance of chemistry as a military asset.

Modern warfare without explosives is difficult to conceive. Explosives are necessary for use as propelling charges in order to reach an enemy many miles away, and without high explosive bursting charges the effectiveness of the projectiles is very much limited.

Probably the first explosive mixtures were those resembling gunpowder, used by the Chinese for rockets and other pyrotechnics, while the earliest use of propellent powder in warfare was at the Battle of Crecy in 1346. The substance then employed, which did not pass from military history until the time of the Spanish War, was ordinary gun powder, composed of charcoal,

sulfur and potassium nitrate and was, supposedly, invented by the Franciscan Friar, Roger Bacon.[1]

For centuries no effort was made to improve upon this means of discharging cannon and rifle shot because it was quite sufficient in explosive power for the type of projectile used. In 1880, however, an underburnt charcoal was substituted for the black variety, causing the powder to burn more slowly and regularly. This type of gunpowder was called brown or cocoa powder from the appearance of the charcoal.[2]

In the meantime chemists in the course of experiments, with quite other objects in view, discovered various explosive substances which proved of great value when modern guns and projectiles came into being. The nineteenth century marked the active application of science to explosives, with the result that this industry developed enormously.

Edward Howard invented fulminate of mercury in 1800 by dissolving mercury in nitric acid, then pouring the mixture into ethyl alcohol. It is a brusque and powerful substance, exploding with great violence on mere impact or ignition. The London gunmaker, Joseph Egg, devised the fulminate of mercury cap, thus using the readily-detonated fulminate to initiate the detonation of less sensitive explosive substances.[3]

1. Hessel,F.A., Hessel, M.S., and Martin, Wellford, Chemistry in Warfare, p. 46.
2. O'Hern, Edward Phillip, Explosives, p. 253.
3. Guttmann, Oskar, Twenty Years Progress in Explosives, p. 263.

In the course of some experiments on highly oxidized bodies, Schonbein nitrated cellulose in 1845 to form guncotton, or nitrocellulose, and recognized at once its importance as an explosive. However, it was bulky, its rate of burning was too fast, and it was unstable due to the presence of impurities which were difficult to remove. In 1865 Abel discovered that pulping the guncotton made it more easily compressed, and what is more, rendered it more stable by removing the impurities. Finally in 1870 Volkmann treated pulped guncotton with a mixture of alcohol and ether, which gelatinized the guncotton and slowed down its rate of burning, thus giving a good smokeless powder.[1]

During this time Sobrero had discovered nitroglycerine in 1846 by the nitration of glycerine, but no practical application of it was made due to its dangerous nature, the inconvenience of dealing with a liquid explosive, and the difficulty in causing it to explode. Alfred Nobel, in 1859-61, found it could be exploded by means of a detonator containing mercury fulminate, and commenced its manufacture. Continual catastrophes caused Nobel to search for means to make the material safer and more convenient to handle, and he discovered in 1867 that Kieselguhr - a siliceous earth - absorbed three times its weight of nitroglycerine, making it usable as an explosive. This combination of nitroglycerine absorbed in kieselguhr he called dynamite.

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1. Marshall, Arthur, Explosives, I, pp. 39, 40, 49

In 1875 he added a very small amount of nitrocellulose to nitroglycerine, forming blasting gelatin which is superior to dynamite because it is impervious to water and is much more powerful, being a mixture of two explosive substances.[1]

Nobel continued his experiments with nitrocellulose and nitroglycerine, and in 1888 invented Ballistite, a smokeless powder consisting of low - nitrated nitrocellulose gelatinized with nitroglycerine. That same year the English adopted cordite as their standard propellant powder - a mixture of highly-nitrated nitrocellulose, nitroglycerine, and vaseline, gelatinized by means of acetone.[2]

Smokeless powders like these furnished most of the ammunition used in the Boer and Russo-Japanese wars. Now every nation uses propellant powders consisting principally of gelatinized nitrocellulose either by itself or mixed with nitroglycerine. At the same time these two conflicts demonstrated conclusively the effectiveness of artillery fire and led to the search carried on by all the great nations, at the turn of the century, for more and more powerful explosives suitable for the larger guns which the alloy steels were making possible.[3]

The first of these, picric acid, discovered by Glauber around 1650 as a result of treating wood with strong nitric acid, and used for many years as a yellow dye, was not known to be explosive until 1805. Even then it was not put to practical use in

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1. Marshall, op. cit., pp. 41-2.
2. Ibid., p. 49.
3. Hessel, op. cit., pp. 46-7.

this way until Sprengel discovered in 1871 that it could be detonated with a fulminate of mercury cap. In 1885 Turpin pointed out the great advantages of using picric acid for filling shells, in consequence of its stability, insensitiveness, and violence. Other high explosives of the time were mostly too sensitive to use in shells: they were liable to explode in the bore of the gun from the shock of discharge. For this reason gunpowder only was previously used, and it still forms the bursting charges of shrapnel and other sorts which only require a moderate disruptive power. Picric acid, however, is nearly as insensitive as black powder and could therefore be used with safety for shells. In fact it requires a very powerful detonator to insure complete detonation, and must be melted so that it may be more readily detonated. With various modifications picric acid has been adopted in almost every country for this purpose.[1]

There are certain basic disadvantages to picric acid, however, which required the continuation of the search for suitable high explosives. The metallic salts of picric acid formed dangerous, sensitive compounds which made necessary the varnishing of the inside of each shell; the melting point was too high for convenient melting; it was an acid, and as such could displace other acids; it had a bitter taste, making it difficult to manipulate; and it dyed the skin yellow.[2]

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1. Marshall, op. cit., I, pp. 49-50.
2. Guttmann, op. cit., p.270.

Chlorate mixtures have at all times fascinated inventors on account of the large amount of oxygen stored up in potassium chlorate, which can be given off so readily, but because they are so sensitive and unstable, all attempts to manufacture chlorate explosives resulted in disaster. In 1897 Street invented Cheddite, the only usable chlorate explosive. It consists of potassium chlorate mixed with castor-oil in which aromatic nitro-compounds are dissolved, thus overcoming the great sensitiveness of chlorate mixtures.[1]

The Germans some time prior to 1910 - it is not known when, as their work along these lines was kept very secret - discovered TNT (trinitrotoluene), one of the most potent explosives. It is known that at the Philadelphia Exposition in 1876 their chemical display contained trinitrotoluene as a dye intermediate but its explosive properties had not been discovered then. Its basic constituent is toluene, a coal tar intermediate, made readily available by Germany's great dye industry, and the explosive is made by the comparatively simple process of nitration with nitric acid.[2]

It is one of the most stable of the high explosives; relatively safe to manufacture, load, transport, and store; is non-hygroscopic; has no tendency to form unstable, dangerous compounds with metals; and has powerful, brisant (shattering), explosive properties.[3]

1. Marshall, op. cit., I, pp. 35,46.
2. Hessel, op. cit., p. 48.
3. United States Ordnance Department, Military Explosives, p.98.

So much of this highly effective substance was used by the Allied armies during the war that there was, finally, a shortage of toluene and substitutes had to be found. One of the best of them was amatol, a mixture of TNT and ammonium nitrate which the Germans had used early in the war. Amatol is often a 50/50 mixture, fluid when hot, and is cast directly in the shell; or it is a mixture of 80% ammonium nitrate and20% TNT heated to the consistency of slightly damp brown sugar, and is pushed into the shell by a miniature helical conveyor known as an extruder. Amatol is hygroscopic, but is insensitive to blows or friction; it does not tend to form dangerous compounds with metals other than copper or tin, and has approximately the same rate of detonation and strength as TNT.[1]

Then there was the secret high-explosive of the United States Army, the composition of which was not known until after the war. This was Explosive "D" (named for Colonel Dunn of the U. S. Army who proposed its use) or ammonium picrate, made by mixing picric acid in hot water solution with strong ammonia. Having a marked insensitiveness to shock and friction, and far less liable than picric acid to form unstable metallic salts, this substance has an explosive strength only slightly less than that of TNT.[2]

Because such relatively insensitive explosives were detonated with difficulty by the regular detonators, the aid of a so-called booster, or intermediate charge was required. This charge

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1. Ibid., p. 148; Hessel, op. cit., p. 48
2. Hessel, op. cit., p. 48.

consisted of a high explosive which was more powerful and more sensitive than the bursting charge. Thus the detonator set off the booster which, in turn, set off the main bursting charge.[1]

As a booster, tetryl (trinitrophenylmethylnitramine) - prepared by the nitration of dimethylaniline - was developed. One of the most powerful of all military explosives, it has the strength and brisance (shattering effect) to make a fine bursting charge, but it might not withstand the shock of discharge and might cause a premature explosion. TNA (tetranitroaniline), prepared by the nitration of aniline, is used as a substitute for tetryl. It is the strongest of all solid high explosives, but is more sensitive than TNT and more expensive.[2]

Chemists are continually searching for more and better explosives. The nitrostarches, aliphatic nitro compounds, trinitroresorcinal, trinitrobenzaldehyde, dinitrobenzene, and hexanitrodiphenylamine have been studied and tested for use as main bursting charges; and pentryl and pentaerythritol nitrate, for use as boosters. Lead azide has become a satisfactory substitute for mercury fulminate, and experiments are also being conducted with diazodinitrophenol for use as a detonator.[3]

The various high explosives which may be considered as suitable in their general character for military use may differ widely from each other in such properties as (1) sensitiveness

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1. Hessel, op. cit., p. 33.
2. U. S. Ordnance Department, op. cit., pp 130-2, 137-8.
3. Ibid., pp. 130-2, 140-4.

to mechanical shock, to heat, or to the action of detonators, (2) the rate at which they detonate or liberate their energy, (3) the total amount of energy available, etc. In the selection of an explosive for a given purpose, as e.g., the bursting charge for high explosive shell, for bombs, or for grenades, the properties of the explosive must be considered from many standpoints, together with the nature of the work which the explosive is to perform. The explosive must have the necessary strength and quickness, or brisance, to produce proper fragmentation or other desired effect; it must be sufficiently sensitive to be detonated by the action of the detonator or booster with which it is to be used; it must be chemically stable and not appreciably hygroscopic, so that it can withstand storage; it must be reasonably insensitive to mechanical shock and friction, so that it will not be unduly dangerous to load; it mustbe capable of being manufactured without special danger, and at reasonable cost from readily available raw materials, so that its war-time procurement will be possible. There are also special requirements for explosives for various purposes. Thus, an armor-piercing shell filler must be sufficiently insensitive to withstand the shock of impact of the shell against armor plate, so that it will not detonate before passing through the plate; the bursting charge for high explosive bombs should be able to withstand the penetration of rifle bullets without detonating, etc. [1]

All explosives are solid or liquid substances which, on the application of an outside force such as heat or a blow, undergo

1. U. S. Ordnance Department, op. cit., p. 9

decomppsition with great rapidity and with the evolution of gas and heat.[1] Explosives are divided into two main classes: the propellants and the high explosives. The propellants, often called low explosives, include the gunpowders, and their combustion is a surface action, proceeding from layer to layer and causing a progressive emission of gas, thus propelling the missile from the gun.[2] The high explosives include the main bursting charges, the detonators, and the boosters; and their combustion consists of the breaking up of the initial molecules, giving rise to an explosive wave which is transmitted with great velocity in all directions throughout the mass and causing its almost instantaneous conversion into gas. Thus, a high explosive could not be used as a propellant because the sudden conversion into a gas would develop a high pressure which would rupture the gun. The main bursting charges are the relatively insensitive high explosives and constitute the main filling of the shell. The detonators are the most sensitive, and are used to initiate the detonation of the main burating charges. The boosters are sensitive intermediate charges which assist the detonators in setting of the relatively insensitive main bursting charges.[3]

The chemical composition of military explosives is quite unique in that practically all of them are nitrates or nitro bodies - mercury fulminate, for instance, is made from metallic

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1. Marshall, op. cit., I, p. 1.
2. O'Hern, op. cit., p. 250.
3. O'Hern, op. cit., p. 250.

mercury, nitric acid, and ethyl alcohol; nitrocellulose is made by treating cotton with a mixture of nitric and sulfuric acids; nitroglycerine is the product of the nitration of glycerine; TNT is produced by the action of nitric acid on toluene, a coal tar product, etc. Yet it is not nitrogen but oxygen which is the real explosive. The explosion of such nitro compounds is a rapid combustion in which the oxygen comes from within the molecule itself. Because the nitro groups supply this oxygen, the explosive force increases with the number of nitro groups.[1]

Furthermore, with the exception of black powder and potassium chlorate, all the military explosives are organic compounds, thus consisting of the elements carbon, hydrogen, oxygen, together with nitrogen. On detonation the organic compounds decompose and are converted principally into the gases carbon dioxide, carbon monoxide, and nitrogen, together with small amounts of hydrogen, oxygen, methane, ammonia, and nitric oxide. Potassium chlorate decomposes into oxygen and potassium chloride. Black powder, which contains potassium nitrate, charcoal, and sulfur, is converted into carbon dioxide, carbon monoxide, and nitrogen, together with small amounts of hydrogen sulfide, methane, oxygen, and hydrogen; also as a result of the explosion, the solid products potassium carbonate, potassium sulfate, potassium sulfide, and sulfur are formed.[2]

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1. Hessel, op. cit., p. 49.
2. Marshall, op. cit., I, pp. 1-6; O'Hern, op. cit., pp. 250-2.

TABLE I GIVING THE MILITARY EXPLOSIVES, THEIR CHEMICAL FORMULA, AND THEIR USE.

EXPLOSIVE	FORMULA	USE
1.Black(brown) powder	KNO_3, C, S	Propellant
2.Smokeless powder	$\left[C_6H_7O_2(ONO_2)_3\right]_x$ and $CH_2(ONO_2)CH(ONO_2)CH_2(ONO_2)$	Propellant
3.Picric acid	$C_6H_2(OH)(NO_2)_3$	Bursting charge
4.Ammonium picrate	$C_6H_2(ONH_4)(NO_2)_3$	Bursting charge
5.TNT(trinitrotoluene)	$CH_3C_6H_2(NO_2)_3$	Bursting charge
6.Nitrostarch	$\left[C_6H_7O_2(ONO_2)_3\right]_x$	Bursting charge
7.Trinitroresorcinal	$C_6H(OH)_2(NO_2)_3$	Bursting charge
8.Trinitrobenzaldehyde	$C_6H_2(CHO)(NO_2)_3$	Bursting charge
9.Dinitrobenzene	$C_6H_4(NO_2)_2$	Bursting charge
10.Hexanitrodiphenylamine	$\left[C_6H_2(NO_2)_3\right]_2NH$	Bursting charge
11.Tetryl	$C_6H_2(NO_2)_3N(CH_3)NO_2$	Booster
12.TNA(tetranitroaniline)	$C_6H_2(NO_2)_3(NHNO_2)$	Booster
13.Pentryl	$C_6H_2(NO_2)_3N(NO_2)(CH_2CH_2ONO_2)$	Booster
14.Pentaerythrital nitrate	$C(CH_2ONO_2)_4$	Booster
15.Mercury fulminate	$Hg(CNO)_2$	Detonator
16.Lead azide	PbN_6	Detonator
17.Diazodinitrophenol	$C_6H_2(NO_2)_2(N_2O)$	Detonator

B. Projectiles

Originally cannon balls were of cast iron, spherical, and solid, then hollow with a bursting charge of gunpowder or with incendiary material. In the Civil War a cylindrical shell with a pointed nose was used. The cast-iron, however, put definite restrictions upon the weight and filler cavity. Today steel alloy projectiles are used.[1]

A shell explosion is really a series of chemical explosions: (1) the violent decomposition of the fuse or detonator caused by the shell's impact, (2) the force of the first explosion sets off the second, that of the booster charge, which in turn transmits vibrations of sufficient violence to (3) explode the bursting charge, most stolid of the three chemicals contained in the shell. In ordnance this is called an explosive train.[2]

High explosive shells usually have about 3 to 30 percent of their weight in high explosives. The smaller percent is for fragmentation; the larger, for demolition. They usually have a fuse which causes an explosion upon impact, but with just enough delay to secure penetration well into the interior of the trench or other hostile cover.[3]

The trench howitzer shell or trench mortar shell is a shell of considerable caliber thrown with a comparative low velocity from a trench or other concealed position. The shock of dis-

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1. Hessel, op. cit., pp. 30-31.
2. Ibid, p. 33.
3. O'Hern, op. cit., p. 261.

charge from a trench mortar is comparatively slight, hence the shell does not have to be constructed so strongly as those for ordinary guns and mortars. Also somewhat more sensitive explosives can be used. Such shells are often used to break wire entanglements.[1]

Chemical shells - gas, smoke, and incendiary - are projectiles filled with chemical agents and their design differs little from the high explosive shell. Except for the special projectile for the chemical mortar, chemical shells are used by the same field artillery weapons. They contain only a small bursting charge of high explosive for breaking open the shell and scattering the contents.[2]

Armor-piercing projectiles have a long-pointed outer covering for the head, which reduces air resistance in flight and enables the projectile to reach its target with a higher striking velocity, and a short inner cap of hardened alloy steel, which gives the point support and enables the projectile to get through a hard-faced plate unbroken. There are two types of such projectiles: (1) the armor-piercing shell, which carries a large bursting charge and has a quick-acting fuse which detonates the explosive immediately upon impact with armor plate; it is used against light-armored vessels or the upper works of heavily armored craft, because it drives in the thin plates and destroys those parts not protected by heavy armor; (2) the armor-piercing shot, thick walled, with a small bursting charge and delay-action

1. Marshall, op. cit., II, p. 563.
2. Hessel, op. cit., p. 32.

fuse, to permit the projectile to pass through the plates of heavily armored vessels and detonate after reaching the ship's interior.[1]

Common shrapnel contains a case, closed at the rear, filled with lead balls and carrying a fuse set to cause the balls to be expelled while the projectile is in the air immediately in front of the enemy's position. The balls are expelled by the action of a charge of powder carried in the rear of the balls, and ignited by a flame from the fuse passing down a central tube communicated with the powder charge.[2]

High explosive shrapnel combines the principles of both the high explosive shell and common shrapnel. The head carries a high explosive charge, and the matrix surrounding the balls is a high explosive capable of being detonated by the detonation of the head. This projectile carries a time fuse and base charge as does the common shrapnel. For use as such the head and balls are expelled without a detonation occurring, the matrix serving to produce smoke as does that of the common shrapnel. The head continues in flight and detonates on impact. TNT is usually used in the head and matrix, and mercury fulminate in the detonator. If the projectile should strike without having functioned as common shrapnel, the head and matrix would detonate together, thus giving the effect of the high explosive shell.[3]

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1. Ramsay, Hobart Cole, Elementary Naval Ordnance and Gunnery, pp. 108-112.
2. O'Hern, op. cit., pp. 261-263.
3. Ibid., p. 264.

There are three types of bombs: (1) fragmentation, (2) demolition, and (3) chemical. Their construction closely resembles that of the shell similarly employed. All three contain a bursting charge of high explosive plus a fuse or detonator which operates on impact. Only the outer body of the bomb is different: it has fins and an arming wire apparatus by which it is released from the bombing plane.[1]

Fragmentation bombs are used by pursuit and attack planes and by attack bombers against troops, anti-aircraft emplacements, and air bases. Such bombs have a considerable incendiary effect. It is also possible to coat the inside walls of such bombs with poisonous substances which make the tiniest wound from the scattered fragments possibly fatal.[2]

Demolition bombs are used against important objects, like high buildings, forts, ships, and underground structures. They are usually of the armor-piercing type, but are highly incendiary also. Many now contain liquid oxygen, a potent explosive agency. Known abroad as LOX it is composed of liquid oxygen, soft-wood carbon, and ammonium phosphate.[3]

Chemical bombs contain gases or incendiary materials. Gas bombs are filled with gases in solid or liquid form, which are converted to the gaseous stage by the high temperature of the explosion. Incendiary bombs are of the scatter or intensive type.

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1. Hessel, op. cit., p. 39
2. Idem.
3. Idem.

The former is used to set fire to readily combustible materials, as grain, woods, and flammable buildings. The latter is used to set fire to buildings or heavy structures.[1]

Torpedos and mines are similar except that mines are stationary and torpedos are propelled. The torpedo is driven by an air engine actuated by compressed air which is heated by means of a burner so as to increase the power. It is launched from a tube by a charge of smokeless powder, and a gyroscope keeps the direction constant. In the head there is a charge of explosive which is fired by percussion when the torpedo strikes.[2]

There are four types of mines: (1) observation mines, which are connected by cables with an observation point on shore and are fired by the observer when the enemy's ship is over the mine or within the destructive area; (2) electro-contact mines, which are also connected by cables, but may explode automatically when struck, although they usually are fired from a shore station where they indicate by an electric indicator the contact of a passing ship; (3) mechanical-contact mines, which are not connected in any way with the shore and explode by contact with the vessel; (4) electro-magnetic mines, which are not connected with the shore, and whose feelers, broadcasting the shock of an approaching ship- when about twenty to thirty feet away - touch off an explosive charge in the mine.[3]

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1. Hessel, op. cit., p. iii.
2. Ramsay, op. cit., pp. 288-291.
3. Williams, Henry Smith and Williams, Edward Huntington, Modern Warfare, p. 123; Hessel, op. cit., p. 110.

With small arms (weapons of less than one inch caliber) a blow by the striker on the cap ignites the cap and the flame fires the powder directly. A complete round of ammunition consists of (1) a cartridge case containing a percussion primer of mercury fulminate, potassium chlorate, and antimony sulfide; (2) a charge of propellant powder; (3) a bullet. There are four types of bullets: (1) regular bullet, formerly consisting of a cupro-nickel jacket lined with a thin lead coat and with a special heat-treated steel core, now made up of lead alloys, and experiments going on with regard to the use of zinc; (2) armor-piercing bullet, consisting of a chromium alloy surrounded by a gilding-metal jacket and with a tungsten core; (3) tracer-bullet, consisting of a cupro-nickel shell with a lead core, and a rear chamber containing a compressed column of a pyrotechnic mixture, usually barium peroxide and magnesium; (4) incendiary bullet, which is the same as the tracer bullet except that it carries phosphorus in the nose of the bullet and has a lead plug and a special low-melting solder.[1]

Grenades were used as early as 1400 and looked like pomegranates - for which they are named. There are three types of grenades: (1) fragmentation grenades, (2) gas irritant grenades, and (3) smoke grenades. The fragmentation grenades are made of cast iron and grooved up, down, and around to insure complete breaking up. In the chemical grenades the cylindrical case is of

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1. Hessel, op. cit., p. 37; Marshall, op. cit., II, p. 549; Boston Evening Traveller, Death-Dealing Zinc Bullet Patented p. 32.

tin plate, containing holes covered with adhesive tape through which the vapor can issue. Smoke grenades do not contain holes, but contain a bursting charge which by shattering the body scatters the contents. Today they all look like pineapples.[1]

When a fragmentation grenade is thrown, a lever is pulled which explodes a primer which ignites a fuse timed to burn five seconds and then set off the igniting charge. This in turn explodes the bursting charge, rupturing the cast iron body and scattering the fragments.[2]

There are also rifle grenades. They have a rod which goes down to the barrel of the rifle and are fired with a special cartridge having no bullet. A safety pin is removed before firing, and after the grenade has travelled some distance, some vanes attached to it release the striker by rotating, and the impact hits the detonator.[3]

1. Hessel, op. cit., p. 38.
2. Idem.
3. Marshall, op. cit., II, pp. 564-567.

C. Fuses

A fuse is used to ignite the detonator. It is a device by which a flame is communicated to the detonator either after an interval of time, or by operation conducted at a distance. Black powder, gunpowder, and certain explosives are used in the various fuses.[1]

Shell fuses consist of percussion and time fuses. Percussion fuses, either in the nose or base of the shell, work on one principle, namely, when the shell strikes an object, the sudden retardation either causes a pin to strike a percussion cap or makes the cap fall on to the pin. The flash from the cap ignites some priming composition, and so the ignition is communicated into the interior of the shell proper. The fuse may be provided with a delay arrangement - a small pellet of combustible matter which must be burnt through before the flame can reach the shell. This causes the shell to explode only after it has travelled some distance through the armor plating of a ship, for instance.[2]

Time fuses are used mostly for shrapnel, where the shell is designed to burst in the air at a predetermined distance. Here, the safety pin is removed prior to the shell's insertion in the gun. The exploding propellant powder sets the weighted hammer - or striker - back sharply against the primer. This primer fires a train of special powder (black powder) which burns slowly along a tortuous channel of timing rings until it reaches and explodes

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1. Marshall, op. cit., II, p. 535.
2. Ibid., p. 546.

the detonator set in the booster charge which in turn explodes the bursting charge of the shell. Regulating the length of the channel regulates the time of the explosion. Mechanical time fuses, having the same effect, are being used more and more.[1]

Mechanical fuses are fired by mechanical action, as by pulling a wire or cord which releases a striker which is driven by a spring on to a percussion cap. Such devices are little used, except for fuses for firing artillery shell.[2]

In electric fuses the heat generated by an electric current is utilized to fire a suitably constructed fuse, and this ignites a detonator, which in turn explodes the charge. There are two classes of electric fuses: (1) high tension fuses, where a spark is made to pass between two metal poles and ignite a primary material such as a tuft of gun-cotton or a mixture of potassium chlorate and antimony sulfide, and (2) low tension fuses, where there is a small bridge of fine wire - usually platinum - which is heated to incandescence by the current, thereby igniting the primer. This type is used now, because it can be tested before using, while the high tension type can be tested only by firing, which destroys it.[3]

1. Hessel, op. cit., p. 34
2. Marshall, op. cit., II. p. 546.
3. Ibid., p. 543.

CHAPTER IV PYROTECHNICS

A. Composition

Pyrotechnics, known in time of peace as fireworks, are filled with mixtures which burn energetically and contain in themselves the oxygen necessary for combustion. The mixtures are practically identical with some of those that are used as explosives, and in some circumstances are liable to explode. In fact, many varieties of pyrotechnics are made to explode, in order to produce a report.[1]

Pyrotechnic mixtures usually consist of an oxidizing agent, combustible materials, a specific chemical compound to produce the color desired, and a binding material.

Potassium nitrate and potassium chlorate are used as oxidizing agents. They carry a large percent of oxygen which is readily given up. Potassium chlorate is sensitive to heat and friction, hence it is liable to cause a premature explosion. Also, since it is the salt of a weak acid, easily replaced by other acids and extremely unstable in the free condition, any combination which contains free acid or develops free acid by close association of the materials, may produce a premature explosion. Because chlorate mixtures are somewhat difficult to ignite, a primer of some mixture such as mealed powder is used.[2]

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1. Marshall, op. cit., II. p. 607.
2. Faber, Henry B., Military Pyrotechnics, III, pp. 11, 140.

Charcoal and sulfur are the combustibles used. They not only serve as fuel to be oxidized by the available oxygen contained in the other constituents, but act as deterrents where otherwise the process of combustion would be too rapid.[1]

The chemical compounds which produce a specific color are usually present as chlorates, nitrates, carbonates, and other compounds, all containing additional oxygen, to insure complete combustion. Because the chlorates are so unstable, in many cases they are replaced by the more stable perchlorates. Sodium salts are used to produce a yellow color. Barium nitrate and barium chlorate gives a green color. During decomposition barium chlorate becomes barium chloride, which causes an even better green color. Strontium nitrate and strontium carbonate give a red color. Strontium carbonate absorbs any free acid which may exist in the composition when made, or which may be subsequently produced, thus removing the danger of storing or handling compositions containing potassium chlorate. Copper ammonium sulfate and oxychloride of copper give a blue color; copper carbonate together with strontium nitrate, gives a violet color. Lead compounds and alum also give a blue color. Aluminum and magnesium give a white color, and sometimes a little lead oxide or lead nitrate is added to neutralize the yellow effect due to traces of sodium. Antimony is also used for white fires, antimony sulfide giving a bluish white flame. Arsenic is

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1. Faber, Henry B., Military Pyrotechnics, III, pp. 61,70.

used as arsenic disulfide in smoke tracer compositions, giving off a yellow smoke. Mercurous chloride is often added to increase the luminosity and decrease the rate of burning. Metal filings produce particularly effective scintillations, bits of iron and copper wire giving a green effect and zinc filings, a white color which tends towards a bluish tinge.[1]

Various substances are included in the binding material. The paste usually consists of rye or wheat flour. Tallow, mixed with pitch or resin, softens certain pastes, making them easier to manipulate. Gum arabic, used in powder form, gives consistency and slows down the combustion. Camphor moistens the various compositions and increases the brilliancy of the fire. Shellac is used physically as a binder and chemically as a fuel to be consumed by the oxidizers present, thus affording the necessary heat.[2]

Clay, made plastic with water and molded into desired shapes, serves for plugging cases, etc. The cotton thread used to prepare the fuses and matches is white, and is treated to leave only a small residue of ash after burning. In order to prevent the penetration of humidity, the pyrotechnic mixtures are coated with such varnishes as caoutchouc, copal, shellac, and collodion.[3]

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1. Faber, op. cit., I, pp. 154-157; III, pp. 31, 44, 76, 104, 115, 116, 159, 205: Marshall, op. cit., II, pp. 609-611.
2. Faber, op. cit., I, pp. 155-157; III, p. 184.
3. Ibid., I, pp. 154, 156, 157.

B. Method of Use

Military pyrotechnics are used for illuminating and signalling purposes, generally in the form of shells, rockets, signal pistols, rifle lights, illuminating hand grenades, airplane flares, and position or ground lights.

Star shells are used to illuminate the country at night, and also for signalling purposes. They are similar to shrapnel but contain stars of pyrotechnic composition instead of bullets. This composition is generally a light-giving composition similar to flashlight powders used in photography, namely, mixtures of magnesium or aluminum powders, or both, with potassium nitrate or potassium chlorate or barium nitrate, with or without some binding material. In some cases each star is fitted with a parachute which opens when the shell bursts and prevents the star from falling too rapidly. Star shells are provided with time fuses: when the fuse has burnt the proper time it ignites the priming of the stars and also the bursting charge in the base of the shell.[1]

Night tracers for shell and pistol are filled with a pyrotechnic mixture which is ignited as the shell or bullet leaves the gun, making the course of the projectile visible like a rocket. Day tracers for shell are filled with a dark-colored liquid, which is ejected during flight as a fine spray.[2]

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1. Marshall, op. cit., II, p. 564.
2. Idem.

The rocket consists of a tube, open at one end, into which is rammed a black powder mixture. A large conical hole is made in the composition and a piece of quick match or other igniting device is applied. The composition burns from the surface of the conical hole outwards, and the products of combustion, largely gaseous, escape at a high velocity through the constricted opening, with the result that the rocket is driven forwards. The charcoal is often not powdered very finely, in order that a good trail of sparks may be formed as the rocket rises. The ordinary rocket is attached to a stick which projects behind and serves to maintain the direction as it travels through the air. The war rocket contains a tail piece with three conical openings or vents cut away on one side, so that the gas issuing from the body meets with resistance on one side only, thus causing the rocket to rotate. The rotation keeps the rocket steady, eliminating the stick.[1]

Signal rockets have a cardboard case and a chamber in the forward end, separated by a plug of clay or other material through which passes a piece of quick-match. The chamber contains gunpowder and a number of stars, composed of white or colored light composition and primed with mealed powder. When the rocket has reached its maximum height and all the rocket composition has burned away, ignition is conveyed by the quick-match to the powder, which explodes and bursts the walls of the

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1. Marshall, op. cit., II. p. 607-608.

chamber. The stars then fall down burning brightly.[1]

The sound rocket, also used for signalling, has a small charge of high explosive which is fired by means of a detonator as soon as the rocket composition has burnt away.[2]

Light rockets are used to light up the landscape and reveal the enemy's position at night. Each rocket generally contains a single star composed of light composition somewhat similar to that used for photography. The stars are sometimes provided with parachutes.[3]

Golden rain is made by mixing powder, such as is used for rockets, with crushed iron or steel turnings or borings. These materials are often added to the rocket mixtures in order to produce a more brilliant trail. Magnesium or aluminum powder gives white sparks; copper, greenish sparks; zinc, bluish-white sparks; and iron, red sparks.[4]

The signal pistol is specially designed and contains a cartridge, holding a signal star, which is propelled about 300 feet and burns for from six to eight seconds. Some cartridges can be lighted the instant they leave the pistol; illumination thus begins at the moment of discharge, continuing throughout the trajectory. Other cartridges are fitted with a delay fuse, by which the ignition is effected only when the star reaches its

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1. Marshall, op. cit., p. 608.
2. Ibid., p. 609.
3. Idem.
4. Ibid., p. 611.

limit of height.[1]

Rifle lights are used for illumination or signalling. When used for illumination, white or colored lights are suspended from a parachute; when used for signalling, small briquetts of composition are used which burn with a brilliant light and produce a meteor effect. The light is fired from a mortar or discharger, which device is attached to the muzzle of a rifle barrel. The light is shot out by means of the explosion of a blank cartridge in the rifle barrel, which causes the expulsion of the light from the mortar and at the same time detonates a sensitive cap. The cap in turn ignites a time fuse in the light which is regulated to fire the expelling charge, which charge subsequently lights the illuminating or signalling composition.[2]

Illuminating hand grenades are used at night to repulse wave attacks against intrenchments. When thrown in front of the advancing enemy, the light from their combustion renders possible precise aim in firing. The grenade is filled with a light composition and fired in the same manner as explosive grenades.[3]

The airplane flare is used to illuminate large areas. It consists of a metal container holding a large silk parachute to which is attached a case of compressed composition that will burn with a white light. The flare is attached to the under side of the plane and when released by a lever, the pinwheel in the

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1. Faber, op. cit., I, p. 186; II, p. 195.
2. Ibid., II, pp. 150-151.
3. Ibid., I, pp. 188-192.

igniting end of the flare is set in motion, revolving at high speed, caused by the resulting upward rush of air. The stem of this pin wheel revolves with the wheel and is guided forward by means of proper threading until a point is reached where the disengagement of the threads allows the stem to be forcibly pushed inward to strike a detonating cap which lights the firing charge. This charge - usually black powder - expels the contents of the flare and at the same time ignites the composition.[1]

A position or ground light is used to indicate the location of trenches to aerial observers. It consists of a small cylinder loaded with an illuminating mixture. The cylinder has a cover of tinned iron, through the center of which is an orifice that allows for the ignition of the charge. In firing the light a striker, which is a small cardboard strip coated on one side with a striking composition, is rubbed across a blob of quick-firing mixture. The blob envelopes a fuse or match, which carries the fire to a primer of first fire placed on top of the color producing composition in the can.[2]

1. Faber, op. cit., II, p. 99.
2. Ibid., II, pp. 205.

CHAPTER V CHEMICAL AGENTS

A. Introduction

From the dawn of antiquity to the present century men have fought their battles by physical blows, and it was not until the World War that the history of organized conflict recorded a deviation from this fundamental principle of battle.

The introduction of toxic gas led to an examination of practically every compound in the whole category of chemistry that offered any promise of utility, and to the actual trial in battle of scores of chemical agents. The result was chemical warfare.

The term "chemical agents" is applied to all those chemical substances used in warfare to produce some definite, direct chemical action on the human body, or to generate a screening smoke, or incendiary effect. None of the chemical agents are explosives. There are three major types of chemical agents, as follows: (1) the gases, which produce a physiological action on living tissues, (2) the smokes, which produce an artificial fog in air, (3) the incendiaries, which set fire to flammable material.

History records numerous early but abortive attempts to utilize the powers of chemistry for military ends. With the exception of Greek fire, none of them produced important results. The value of chemicals as war weapons had attracted the serious speculation of military minds as early as the Civil War, but no practical progress was then made because of the then undeveloped

state of the chemical industry. The use of chemicals as warfare agents was not practicable, even though the possibilities may have been recognized, until the chemical industry had attained sizeable proportions.

But during the decades preceding the World War the chemical industry, particularly in Europe, had been expanding apace. A remarkable feature of this new major industry was the tremendous development of dye production, which during the early years of the twentieth century largely centered in Germany. In 1913 the world production of dyes reaches approximately 150,000 tons, of which Germany controlled three quarters, producing at the same time more than eighty-five percent of the intermediates entering into the finished dyes. These intermediate products could also be used in compounding military chemical agents, and at the same time the dye factories provided both technical skill and manufacturing equipment needed for the production of these substances. With but one or two notable exceptions, all of the war gases used in the World War were produced by the dye industry. This explains the military significance of the dye industry.[1]

The basic chemical industries, producing nitrogen compounds, chlorine, sulfuric and nitric acids, and the alkalies, had attained major proportions before the beginning of the war, especially in Germany. Chlorine was being produced in Germany at the rate of tens of thousands of tons annually. The highly

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1. Prentiss, Augustin M., Chemicals in War, p. XVI.

developed coal-tar industry, as well as facilities for production of arsenic, bromines, and phosphorus, stood ready to furnish important contributions to war effort. Only the urge of dire military necessity was needed to insure the advent of chemical warfare. This was brought about when Germany's planned short-duration campaign failed and there was a serious depletion of supplies of explosive ammunition. Germany was then obliged quickly to mobilize her national industries behind her armies.[1]

The introduction of chemicals in war has changed the character of modern combat and vastly accelerated the evolution of military weapons. First there was the crucible of war - more than three years of fierce struggle that taxed the chemical resources of the most highly industrialized nations. Then followed the postwar period of evaluation, research, and assimilation. The latter has contributed no less than the former to the early maturity of this new arm of the war.

From the beginning earnest efforts have been made to check this type of warfare. The Hague Conferences of 1899 and 1907 prohibited the use of asphyxiating or deleterious gases and the discharge of projectiles and explosives from aircraft.[2] At the close of the World War the vanquished nations were forbidden to

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1. Lefebure, Victor, The Riddle of the Rhine, ch. 7.
2. Carnegie Endowment for International Peace: Division of International Law, The Hague Declaration (IV,2) of 1899 Concerning Asphyxiating Gases, p. 1; The Hague Declarations of 1899 (IV,1) and 1907 (XIV) Prohibiting the Discharge of Projectiles and Explosives from Balloons, pp. 1-4.

use,manufacture, import or retain poisonous gases, flame throwers, and all analagous liquids, materials, and devices, also armored cars, tanks, and similar constructions.[1] In 1922 the conference on the limitation of armaments at Washington, D.C., between the United States, the British Empire, France, Italy, and Japan, limited naval armament, ostracized the submarine, and formally condemned poison gas.[2] Finally in 1931 the League of Nations prohibited the use in war of asphyxiating, poisonous, and other gases, and also the use of bacteriological methods of warfare.[3] It is unfortunate, however, that warring nations find chemical warfare too effective to heed peace-time attempts to prohibit the use of the same.

1. Prentiss, op. cit., p. 690.
2. Conference on the Limitation of Armament, Washington, D. C. 1921-22, p. 25.
3. League of Nations, Conference for the Reduction and Limitation of Armaments, pp. 1-13.

B. Gases

Physical Factors

Under ordinary field conditions combat chemicals may originally be either solids, liquids, or gases. Actually, a very few are true gases, a few are solids, and the majority are liquids. The term "gas" therefore is practically a misnomer. It is true only in the sense that on expulsion from the container, the liquid is volatilized into a gaseous state and the solid is transformed by the heat of the explosion into a poison gas.

Physical factors determine the persistency of a gas. Persistency is defined as the length of time a chemical agent remains effective at the point of its release. Upon dispersal persistent gases linger for hours or even days with continued strength and effectiveness, while non-persistent gases quickly mingle with the air and lose their effectiveness.[1]

The persistency of any agent depends upon the nature of the agent, weather factors, and the weapon from which it is fired.

Persistent agents have a high boiling-point, slow rate of volatilization and diffusion, and high density. Non-persistent agents have a low boiling-point, quick rate of volatilization and diffusion, and low density.[2]

High temperatures and high wind velocities increase the rate

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1. Fradkin, Elvira, Thekla Kush, Chemical Warfare - Its Possibilities and Probabilities, p. 139.
2. Prentiss, op. cit., pp. 10, 19-23.

of evaporation, hence reduce the persistency of gases. Precipitation is unfavorable because a good rainfall may wash away the gas cloud or hydrolyze the chemical agent. Low atmospheric pressure causes rising air currents which affect the persistency of gases. The direction of the wind is also a factor.[1]

Large explosive charges break the agent up into fine drops and cause quicker evaporation than low explosive charges, while all distillation apparatuses render the agent non-persistent, since it is vaporized during the burning of the munition. Spray apparatus makes a fog of the agent and causes a rapid evaporation due to the large surface exposed.[2]

Chemical Classifications

Certain metals and metalloids possess well-defined toxic properties and they often confer upon their compounds marked physiological activity. Such metals are arsenic, antimony, tin, mercury, lead, and bismuth. Other elements, themselves of indifferent toxicological action, are capable of combining to form groups or radicals which, although they do not always have an actual existence, have the power of giving to their compounds special physiological properties. For example: (1) the hydrogen and hydroxyl ions which form, respectively, the acids and bases; (2) the oxidizing groups SO_3, SO_4, NO_3, P_2O_5; and the reducing groups SO_2, SH, P_2O_3, and CO.[3]

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1. Prentiss, op. cit., pp. 10, 19,-23.
2. United States Chemical Warfare Service, The Story of Chemical Warfare, p.8.
3. Prentiss, op. cit., p. 108.

There are three different classes in accordance with the organization of toxic molecules. Each class is characterized by particularities of molecular structure and common physical properties.

Class I. The atom or the toxic group is combined according to its valence, either with one or several halogens (F,Cl,Br,I) or with one or several radicals (SO_3, SO_4, NO_2, NO_3, CN) but never with an atom of carbon. The substances constructed on this model are mineral compounds and their schematic formula is X-M-X, where X is a halogen or reducing group and M is the toxic atom or group. For example: mercuric chloride, Cl-Hg-Cl.[1]

Class II. The toxic elements (M) are combined with one or several organic radicals (such as CH_3, C_2H_5, C_2H_3, C_6H_5) and are found linked by carbon or by one or several atoms of hydrogen - "the most simple organic radical." These compounds are the organic compounds, many of which merit the name organo-minerals. Their schematic formula is R-M-R, where R is the organic radical and M the toxic atom or group. For example: methyl arsine, CH_3-As=H_2.[2]

Class III. The basic materials combine, in one or several valences, with halogens or with ionizable mineral radicals, as bodies of the first class, and with carbon or organic radicals or with hydrogen, as bodies of the second class. These are the organo - mineral halogens and the primary elements should at least be bi-valent. Their schematic formula is R-M-X. For example,

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1. Prentiss, op. cit., p. 108.
2. Ibid., p. 109.

ethyl mercuric chloride, C_2H_5-Hg-Cl.[1]

Thus, the metals and metalloids account for the toxicity, the organic groups impart the necessary volatility, and the halogens give added weight to the molecule, increasing the vapor density and in many cases giving an instability in the presence of water sufficient to account for the final toxicity. The organic compounds also give to a large number of war gases their characteristic lipoid solubility. Of the three or four most effective compounds used, all are soluble in alcohol, acetone, fats, and oils, and so are able to penetrate the cells of the body with the facility of the anaesthetics and for the same reason.[2]

Physiological Classification

The gases are further subdivided into five groups, depending on their principal action on the body. They are (1) the lacrimators, which cause tears and intense (temporary) eye pains; (2) the lung injurants, which affect the bronchial tubes and lungs: (3) the systemic toxics, which act on the nerve centers, (4) the vesicants, which produce blisters, inflammation and burns, with destruction of tissues; and (5) the respiratory irritants or sternutators, which produce violent sneezing and coughing, with temporary physical disability. Many of the gases have more than one physiological effect.[3]

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1. Prentiss, op. cit., p. 110.
2. United States Surgeon General's Office, Medical Aspects of Gas Warfare, pp. 81-2.
3. Prentiss, op. cit., p. 113.

Lacrimatory Agents

Physically, they are liquids of relatively high boiling points and low vapor pressures. They are, therefore, essentially non-volatile substances that form persistent gases. They are insoluble in water and soluble in fats and inorganic matter.

Chemically, they are closely related, being formed by a central atom of carbon, carrying a halogen and one or several negative groups in which the hydrogen atoms are readily displaced. They consist for the most part of halogenated ketones (bromacetone-CH_3COCH_2Br), halogenated esters (Ethyliodoacetate-$CH_2ICOOC_2H_5$), and aromatic halides (benzyl bromide - $C_6H_5CH_2Br$).

Physiologically, simple lacrimators affect only the eyes, while toxic lacrimators affect the eyes and also exert certain toxic effects against other parts of the body. All toxic lacrimators are lung injurants also.[1]

Lung Injurant Agents

Physically, they are liquids of relatively low boiling points and high vapor pressures. They are, therefore, volatile substances that form non-persistent gases.

Chemically, the simple lung injurants are derived from chlorine, while the toxic lung injurants are derived from arsenic.

Physiologically, the lung injurants act on the pulmonary system, two outstanding effects of which are the destruction of the lung tissue and the filling up of the lungs by liquids drawn from the blood. Toxic lung injurants have a systemic poisoning effect also.[2]

1. Prentiss, op. cit., pp. 129-131
2. Ibid., p. 147.

TABLE II GIVING THE LACRIMATORS IN ORDER OF THEIR CHRONOLOGICAL APPEARANCE IN THE WORLD WAR, THEIR CHEMICAL FORMULA, AND THEIR PHYSICAL STATE.[1]

SIMPLE LACRIMATORS

AGENT	FORMULA	STATE
1.Ethylbromacetate	$CH_2BrCOOC_2H_5$	Liquid
2.Xylyl bromide	$C_6H_4CH_3CH_2Br$	Liquid
3.Benzyl bromide	$C_6H_5CH_2Br$	Liquid
4.Brommethylethyl ketone	$CH_3COCHBrCH_3$	Liquid
5.Ethyliodoacetate*	$CH_2ICOOC_2H_5$	Liquid
6.Benzyl iodide	$C_6H_5CH_2I$	Solid
7.Brombenzyl cyanide*	$C_6H_5CHBrCN$	Solid
8.Chloracetophenone[2]*	$C_6H_5COCH_2Cl$	Solid

TOXIC LACRIMATORS

9.Chloracetone	CH_3COCH_2Cl	Liquid
10.Bromacetone*	CH_3COCH_2Br	Liquid
11.Iodoacetone	CH_3COCH_2I	Liquid
12.Acrolein	CH_2CHCHO	Liquid

1. Prentiss, op. cit., pp.129-144.
2. Also a decided irritant to the upper respiratory passages; in higher concentrations it is irritating to the skin.

* Achieved noteworthy results in the World War.

Systemic Toxic Agents

Physically, they are all light liquids with relatively low boiling points, high vapor pressures, and high volatilities. They are the least persistent of all chemical agents.

Chemically, they are closely related: they are all derivatives of the compound cyanogen (CN). There are two classes: (1) those containing the radical (-C≡N), called nitriles; (2) those containing the radical (-N≡C), called isonitriles or carbylamines.

Physiologically, they are the most active and virulent poisons known. They penetrate the entire circulatory system, act primarily on the nerve centers, and cause deathby paralysis.[1]

Vesicant Agents

Physically,they are liquids with high boiling points, low vapor pressures, and low volatility. They are, therefore, high in persistency.

Chemically, there are two classes: (1) those containing sulfur, and (2) those containing arsenic.

Physiologically, they produce a blistering action on any part of the body with which they come in contact, with destruction of tissues. These agents differ distinctly from the other groups in that they affect any part of the body with which they come in contact, whether the vesicant is present as a vapor, a liquid, or as a solid.[2]

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1. Prentiss, op. cit., pp. 170-171.
2. Ibid., p. 178.

TABLE III GIVING THE LUNG INJURANTS IN ORDER OF THEIR CHRONOLOGICAL APPEARANCE IN THE WORLD WAR, THEIR CHEMICAL FORMULA, AND THEIR PHYSICAL STATE.[1]

SIMPLE LUNG INJURANTS

AGENT	FORMULA	STATE
1.Chlorine*	Cl_2	Gas
2.Methylsulfurylchloride	$ClSO_2OCH_3$	Liquid
3.Ethylsulfurylchloride	$ClSO_2OC_2H_5$	Liquid
4.Monochloromethylchloroformate	$ClCOOCH_2Cl$	Liquid
5.Dimethyl sulfate[2]	$(CH_3)_2SO_4$	Liquid
6.Perchlormethylmercaptan	$SCCl_4$	Liquid
7.Carbonyl chloride(Phosgene)*	$COCl_2$	Gas
8.Trichlormethylchloroformate*	$ClCOOCCl_3$	Liquid
9.Chlorpicrin[3]*	CCl_3NO_2	Liquid
10.Phenylcarbylamine chloride[4]	$C_6H_5CNCl_2$	Liquid
11.Dichlordimethylether	$(CH_2Cl)_2O$	Liquid
12.Dibromdimethylether	$(CH_2Br)_2O$	Liquid

TOXIC LUNG INJURANTS

13.Phenyldichlorarsine[5]	$C_6H_5AsCl_2$	Liquid
14.Ethyldichlorarsine[6]*	$C_2H_5AsCl_2$	Liquid
15.Phenyldibromarsine[7]	$C_6H_5AsBr_2$	Liquid

1. Prentiss, op. cit., pp.147-169.
2. Also a good lacrimator and fairly powerful vesicant.
3. Also a strong lacrimator.
4. Also a fair lacrimator and moderate systemic toxic.
5. Also a strong vesicant and respiratory irritant.
6. Also a strong vesicant and respiratory irritant.
7. Also a slight vesicant and respiratory irritant.

* Achieved noteworthy results in the World War.

Respiratory Irritant Agents (Sternutators)

Physically, they are all solids with high melting points and negligible vapor pressures, and are dispersed by heavy explosive charges in the form of a finely pulverized dust. Such clouds formed last only a few minutes in the open, hence are non-persistent. They are immediately effective, having readily penetrated existing World War masks.

Chemically, they belong to the family of arsines (A_sH_3) and are compounds consisting of a trivalent arsenic atom, which is linked by one valence to a halogen atom, or to a monovalent active group, and by two other valences to two atoms of carbon of two carbonyl groups. For example: diphenylchlorarsine-$(C_6H_5)_2AsCl$, and diphenylcyanarsine-$(C_6H_5)_2AsCN$.

Physiologically, they cause violent sneezing, coughing, and nausea, often accompanied by headache and vomiting. The action, however, is temporary. Many of the other chemical agents have respiratory irritant effects also.[1]

1. Prentiss, op. cit., pp. 202-3.

TABLE IV GIVING THE SYSTEMIC TOXICS IN ORDER OF THEIR CHRONOLOGICAL APPEARANCE IN THE WORLD WAR, THEIR CHEMICAL FORMULA, AND THEIR PHYSICAL STATE.[1]

AGENT	FORMULA	STATE
1.Hydrocyanic acid	HCN	Liquid
2.Cyanogen bromide[2]	CNBr	Solid
3.Cyanogen chloride[3]	CNCl	Liquid

TABLE V GIVING THE VESICANTS IN ORDER OF THEIR CHRONOLOGICAL APPEARANCE IN THE WORLD WAR, THEIR CHEMICAL FORMULA, AND THEIR PHYSICAL STATE.[4]

1.Dichlorethyl sulfide(Mustard gas)[5]*	$(ClCH_2CH_2)_2S$	Liquid
2.Chlorvinyldichlorarsine(Lewisite)[6]	$CHClCHAsCl_2$	Liquid
3.Methyldichlorarsine[7]	CH_3AsCl_2	Liquid
4.Dibromethyl sulfide	$(BrCH_2CH_2)_2S$	Solid

TABLE VI GIVING THE RESPIRATORY IRRITANTS IN ORDER OF THEIR CHRONOLOGICAL APPEARANCE IN THE WORLD WAR, THEIR CHEMICAL FORMULA, AND THEIR PHYSICAL STATE.[8]

1.Diphenylchlorarsine*	$(C_6H_5)_2AsCl$	Solid
2.Diphenylcyanarsine*	$(C_6H_5)_2AsCN$	Solid
3.Ethylcarbazol	$(C_6H_4)_2NC_2H_5$	Solid
4.Diphenylaminechlorarsine	$(C_6H_4)_2NHAsCl$	Solid

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1. Prentiss, op. cit., pp.170-176.
2. Also a lachrimator and strong respiratory irritant.
3. Also a moderate lachrimator.
4. Prentiss, op. cit., 177-200.
5. Also a strong toxic lung injurant.
6. Also a toxic lung injurant and systemic toxic.
7. Also a toxic lung injurant and respiratory irritant.
8. Prentiss, op. cit., pp.201-216.

* Achieved noteworthy results in the World War.

C. Smokes

Smoke is an aerial concentration of minute solid particles resulting from combustion and minute liquid particles resulting from chemical reactions not involving combustion. These phenomena cannot be scientifically classified into any of the three standard physical states of matter. Both are "dispersed" forms of matter known as colloidal suspensions or solutions. The colloidal state of matter is characterized by an intimate mixture of at least two phases - the dispersed phase (here - liquid or solid) and the dispersion medium (here - air). A dispersion of this kind is the regular distribution of one substance into another in such a way that the individual particles of the one substance are suspended separately from each other in the second substance (here -air).[1]

The tactical value of a smoke is measured by its obscuring power, and the term for such measurement is T.O.P. (total obscuring power). This obscuring power is affected by the rate of settling of the minute particles, the humidity, and the temperature.[2]

There are five types of smoke-producing agents: (1) those that produce particles of colloidal carbon suspended in air; (2) those that produce particles of phosphoric acid; (3) those that produce particles of sulfuric acid; (4) those that produce particles of hydrochloric acid; and (5) those that produce particles of zinc chloride.

1. Prentiss, op. cit., pp. 224-225.
2. Ibid., p. 226.

The first type consists of organic materials which, on ignition, burn with the formation of smoke containing particles of colloidal carbon suspended in air. This type is especially suited for naval vessels, the smoke being produced by the incomplete combustion of crude-oil fuel under the boilers of the vessel. The British Type S Mixture, formerly used for the generation of smokes on land, contained potassium nitrate, sulfur, pitch, borax, and glue. Although the mixture was cheap and easily produced, with readily available materials, the T.O.P. was too low and unreliable to warrant any further use.[1]

The second and most useful and efficient type is phosphorus. There are two allotropic modifications of phosphorus, the red, and the "waxy" or white. White phosphorus is the type preferred for shell and bomb fillers. This material, on exposure to the air when broken open by an explosive charge, takes fire and burns by combination with the oxygen of the air, forming phosphoric anhydride (P_2O_5). The anhydride reacts with the water vapor in the air to produce phosphoric acid (H_3PO_4) as a dense white smoke which moves away with the wind. The smoke as formed from white phosphorus is harmless, but the burning phosphorus, if it comes in contact with the human body, produces severe heat burns. Consequently, it helps destroy the morale of the enemy. It has certain disadvantages, however, being difficult to store and handle, and because it is a solid it can not be sprayed.[2]

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1. Prentiss, op. cit., Pp. 232-4.
2. Ibid., pp. 234-6.

The third type of smoke consists of mixtures of sulfur trioxide (SO_3) alone or dissolved in chlorsulfonic acid ($ClSO_3H$). When this type is sprayed into the air it reacts with both liquid or vapor water to produce sulfuric acid, and, when chlorsulfonic acid is used, hydrochloric acid, both of which in turn absorb water from the air to produce fog-like droplets which float for a long distance with the wind. The smoke as such is relatively harmless for short periods of exposure, but for long periods of exposure may cause coughing and irritation of the nose, throat, and lungs. The smoke-producing liquid, if it comes in contact with the human body, will cause a burn similar to strong concentrated acid. Both the smoke and the liquid, in the presence of air and moisture, produce corrosion on metals and rotting of cellulose fabrics (such as cotton) and leather. The smoke itself produces little or no action on woolen clothing. This type includes sulfur trioxide, fuming sulfuric acid, chlorsulfonic acid, sulfuryl chloride, and sulfur trioxide - chlorsulfonic acid mixture.[1]

The fourth type of smoke includes the liquids tin tetrachloride, silicon tetrachloride, and titanium tetrachloride. These compounds when sprayed into the air are hydrolyzed by the water vapor present, forming the hydroxide and hydrochloric acid with the production of dense, white fumes. The smoke formed by tin tetrachloride is less dense, but it is also less corrosive and more penetrant to the gas mask. It is very expensive,

1. Prentiss, op. cit., pp. 238-241.

however, for wartime use. The smoke produced from silicon tetrachloride closely resembles natural fog, and is used as a substitute for tin tetrachloride. Titanium tetrachloride has a high boiling point and not too great volatility, therefore it is peculiarly adapted for use in laying smoke screens from airplanes, since each individual droplet can move through a great distance before it is completely volatilized and destroyed. It is also used as a filler in artillery and mortar smoke-shells. It is expensive, however, tends to clog the spraying apparatus on hydrolysis, and in liquid form has a corrosive action on metals.[1]

The fifth type of smoke is a mixture of solid compounds which, upon ignition, reacts slowly to produce a large volume of white smoke. It does not explode, nor does it require air for combustion. Agents of this type usually contain the following constituents: (1) powdered zinc; (2) chlorinated hydrocarbons, such as carbon tetrachloride or hexachlorethane; (3) an oxidizing agent, such as sodium chlorate or ammonium perchlorate; (4) a substance to absorb the heat of volatilization, such as zinc oxide or ammonium chloride; and (5) an absorbent to prevent the zinc from settling to the bottom of the liquid carbon tetrachloride, such as kieselguhr or magnesium carbonate. These chemicals are combined in such a ratio as to produce zinc chloride, carbon dioxide, and carbon monoxide as a result of the

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1. Prentiss, op. cit., pp. 238-241.

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chemical reaction which takes place. The finely divided zinc chloride makes a white smoke in air, and the smoke as such is harmless.[1]

This type includes the Berger Mixture, the B.M. Mixture, and the HC Mixture. The Berger Mixture is used in smoke candles and consists of zinc dust, carbontetrachloride, zinc oxide, and kieselguhr. It is chemically inert,harmless until ignited, has a long storage capacity, and is easily handled, transported, and operated. The mixture, however, is erratic in burning, does not utilize all the ingredients, has a high reaction temperature which disperses sparks and causes fires, and the smoke is light gray. The B.M. Mixture contains zinc dust, carbon tetrachloride, sodium chlorate, ammonium chloride, and magnesium carbonate. The mixture burns more uniformly and freely, leaves less residue, and the smoke is more persistent, but an air-tight container is necessary to prevent the evaporation of carbon tetrachloride and the absorbents constitute about 25% inert material. The HC Mixture consists of powdered zinc, hexachlorethane; and zinc oxide. The reaction is less violent, no delaying agents are necessary, and the mixture is more stable and more efficient per unit weight than the B.M. Mixture. Hexachlorethane is a solid, thus eliminating the inert absorbent kieselguhr or magnesium carbonate.[2]

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1. Prentiss, op. cit., pp. 241-246.
2. Idem.

Satisfactory and successful colored signal smokes are produced by the volatilization of organic dye materials. Potassium and sodium chlorate are used as oxidizing agents, and lactose and powdered orange shellac as combustibles. The following dyes have been found to give the best smokes: paratoner - red, chrysoidine or auramine - yellow, indigo - blue, indulin - violet, auramine yellow and indigo - green.[1]

1. Fries, Amos Alfred and West, Clarence J., Chemical Warfare, pp. 332-333.

TABLE VII GIVING THE SMOKES IN ORDER OF THEIR TOTAL OBSCURING POWER, AND THEIR CHEMICAL FORMULA.[1]

AGENT	FORMULA
1.White phosphorus	P
2.Titanium tetrachloride and ammonia	$TiCl_4$ and NH_3
3.Sulfur trioxide	SO_3
4.Sulfur trioxide and chlorsulfonic acid	SO_3 and $ClSO_3H$
5.Hydrochloric acid and ammonia	HCl and NH_3
6.HC Mixture(zinc,hexachlorethane, and,zinc oxide)	Zn,C_2Cl_6, and ZnO
7.Silicon tetrachloride and ammonia	$SiCl_4$ and NH_3
8.Titanium tetrachloride	$TiCl_4$
9.Oleum(fuming sulfuric acid)	SO_3 and H_2SO_4
10.Tin tetrachloride	$SnCl_4$
11.Phosphorus trichloride and ammonia	PCl_3 and NH_3
12.Chlorsulfonic acid and ammonia	$ClSO_3H$ and NH_3
13.Silicon tetrachloride	$SiCl_4$
14.Sulfur chloride and ammonia	SCl_2 and NH_3
15.Chlorsulfonic acid	$ClSO_3H$
16.BM Mixture(zinc,carbon tetrachloride,sodium chlorate,ammonium chloride,and magnesium carbonate)	Zn,CCl_4,$NaClO_3$,NH_4Cl, and $MgCO_3$
17.Berger Mixture(zinc,carbon tetrachloride,zinc oxide, and kieselguhr	Zn,CCl_4,ZnO, and kieselguhr
18.Titanium tetrachloride and ethylene dichloride	$TiCl_4$ and CH_2CH_2Cl

TABLE VII GIVING THE SMOKES IN ORDER OF THEIR TOTAL OBSCURING POWER, AND THEIR CHEMICAL FORMULA.(Continued)[1]

AGENT	FORMULA
19.Sulfuryl chloride.....	SO_2Cl_2
20.Chlorine and ammonia.....	Cl_2 and NH_3
21.Arsenic trichloride.....	$AsCl_3$
22.Type S Mixture(potassium nitrate, sulfur,pitch,borax, and glue)....	KNO_3,S,C,$Na_2B_4O_7$, and glue
23.Crude oil.....	----------

1. Prentiss, 6p. cit., p. 246.

D. Incendiaries

The sole purpose of incendiary agents is to set fire to enemy material. Technically, there are four classes of incendiaries, as follows: (1) Spontaneously inflammable materials, which include solids, such as phosphorus and sodium, and liquids, as phosphorus dissolved in suitable liquids; (2) metallic oxides, as thermite; (3) oxidizing combustible mixtures, as barium oxide and magnesium powder, or barium nitrate, magnesium, and linseed oil; (4) flammable materials used as such, as resins, pitch, celluloid, "solid oil," and flammable liquids and oil.[1]

In the first class the solids consist of phosphorus and sodium. Phosphorus is quite effective because it is good for materials easy to ignite and because it destroys the morale of the enemy by inflicting painful burns which are slow and difficult to heal. It is used in bullets, grenades, and shells. Sodium is used as a filling for the German 17.5 cm. incendiary shell. It is ignited by thermite.[2]

The liquids produce a better and more uniform dispersion on explosion of the container. There is more tendency to adhere and penetrate into combustible materials, and a greater chance of igniting them. Phosphorus dissolved in carbon disulfide, to which crude benzene, fuel oil, gas - tar oil, and TNT have been added, is effective, yet safe. It will ignite

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1. Prentiss, op. cit., p. 248
2. Ibid., pp. 251-2.

after a short exposure to the atmosphere, has a positive and effective incendiary action, and is safe to transport and handle. The time of ignition can be regulated by varying the proportions of the ingredients.[1]

Thermite, in class two, consists of iron oxide and finely divided aluminum which, on ignition, are converted to aluminum oxide and metallic iron with the evolution of great heat. The heat is sufficient to raise the temperature to 3,000°C, the resulting slag also prolonging the heating effect when the reaction is finished. The thermite is used packed loosely, and sulfur or celluloid is added to bind it. It is good for igniting and starting the fire, not continuing it, and is used extensively in small unit drop bombs.[2]

In the third class the oxidizing combustible mixtures contain an inorganic oxidizing agent as potassium or barium nitrate, barium or lead oxide, or potassium perchlorate, together with such combustible substances as carbon, sulfur, magnesium, or organic combustibles. They are used in bullets as barium oxide and magnesium powder mixed with alcohol, red lead oxide and magnesium, and red lead oxide and aluminum; in shell as potassium nitrate, sulfur, powdered antimony, and powdered shellac, and as barium nitrate, magnesium, and linseed oil, which acts as a binder and deterrent; and in small unit drop bombs as barium chlorate, aluminum, resin, and asphaltum varnish.[3]

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1. Prentiss, op. cit., 252.
2. Ibid., pp. 254-6.
3. Ibid., pp. 257-8.

During the World War an oxidizing combustible mixture was used quite effectively by saboteurs in the form of the German Blue Pencil. It looked like a common blue pencil sharpened at one end. The interior contained a glass bulb with two compartments filled with sulfuric acid and a celluloid tube filled with potassium chlorate. The glassbulb ended in a slender point, and when this was broken the acid came in contact with the chlorate, causing an explosion. The two materials were separated by a layer of clay which delayed the action for thirty minutes. The operator broke the point of the bulb and buried the pencil vertically in the inflammable material, and had a half-hour to get away. He cut the pencil with a knife about two centimeters from the point, so that if caught he had the appearance of simply sharpening a pencil.[1]

The fourth class of incendiaries includes petroleum oils, carbon disulfide, wood distillation products, resins, pitch, celluloid, and many flammable oils and liquids not spontaneously flammable. They are used as secondary incendiary materials to propagate and prolong the incendiary action of the primary material (usually thermite) in the larger drop bombs and projectiles. They are also used as liquids in flame projectors. Flame projectors generallyuse a liquid mixture of a heavy viscous oil or tar, as water - gas tar, and a more fluid or flammable liquid, as benzene heads or crude benzene. Such a mixture is readily and easily ignited, yet at the same time

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1. Fries and West, op. cit., p. 347.

combustion does not occur to any appreciable extent until the stream has reached its objective, and the specific gravity is not too low. Ignition is effected by means of a hydrogen pilot lamp at the nozzle: it is non-luminous when not in action and gives positive action when needed. "Solid oil" is a solidified oil mixture, with a small percent of liquid of low fire point, which starts the burning off, and a large percent of liquid of high fire point, which ignites from the liquid of low fire point and continues the burning.[1]

The use of incendiaries on the war field is becoming progressively more limited, while their use on cities by planes is becoming progressively more extensive.[2]

1. Prentiss, op. cit., pp. 259-261.
2. Ibid., p. 262.

TABLE VIII GIVING THE INCENDIARIES AND THEIR CHEMICAL FORMULA.[1]

AGENT	FORMULA
1. Barium nitrate, magnesium, and linseed oil	$Ba(NO_3)_2$, Mg, and linseed oil
2. Barium peroxide and magnesium	BaO_2 and Mg
3. Thermite	8Al and $3Fe_3O_4$
4. Sulfur thermite	8Al, $3Fe_3O_4$, and 9S
5. Modified thermite	3Al, $6Ba(NO_3)_2$, and $8Fe_3O_4$
6. Potassium perchlorate and paraffin.	$KClO_4$, and C_nH_{2n+2}
7. Sodium	Na
8. White phosphorus	P
9. White phosphorus in carbon disulfide	P in CS_2
10. Solidified hydrocarbons	----------
11. Petroleum oils, carbon disulfide, wood distillation products, resins, pitch, celluloid, and many flammable oils and liquids not spontaneously flammable	----------

1. Prentiss, op. cit., p. 7.

E. Tactical Use of Chemical Agents

The chemical agents are also classified according to their tactical use, as follows: offensive gas, defensive gas, harassing gas, blanketing smoke, screening smoke, intensive incendiary, and scatter incendiary.

The object of the offensive gas is to inflict casualties. The ideal offensive gas should have the following technical requirements: (1) readily available raw materials, (2) ease of manufacture, (3) chemical stability, (4) non-hydrolyzable, (5) non-polymerizable, (6) should withstand explosion without decomposition, (7) a solid at ordinary temperatures, (8) high boiling point and low vaporpressure, if it is a liquid, (9) a specific gravity of about 1.5, (10) a melting point above maximum atmospheric pressure, and (11) a vapor density greater than air. It should also have the following tactical requirements: (1) high toxicity, (2) multiple effectiveness, (3) non-persistency, (4) effects of maximum duration, (5) immediate effectiveness, (6) insidiousness in action, (7) volatility (maximum field concentration), (8) penetrability, (9) invisibility, and (10) odorlessness.[1]

Phosgene comes closest in meeting these requirements. It fails in the following: it lacks multiple effectiveness (a lung-injurant only), it is not odorless, with water vapor it forms a white steaming cloud, it hydrolyzes with water, and it is a gas and has to be artificially cooled to be filled.[2]

1. Prentiss, op. cit., pp. 35-46.
2. Idem.

The defensive gas is used to contaminate certain areas and render them dangerous to traverse or occupy. It has the same requirements as the offensive gas except that it should be persistent and effective in low concentrations. Mustard gas is the best agent of this type. It is not effective immediately, however, has a faint odor, hydrolyzes, and is a liquid in the summer and a solid in the winter.[1]

The harassing gas is used to harass the enemy and reduce the combat efficiency of his troops by forcing them to mask with subsequent reduction in their mobility, physical stamina, and morale, and by imposing a constant need for vigilance. The ideal harassing agent has the same requirements as the defensive gas, and diphenylchlorarsine comes closest to the standards. It has the following failings: it is not very persistent, has only one effect - sternutatory, is difficult to make and disperse, has a detectable odor, a high melting and boiling point, and a low vapor pressure.[2]

There are two types of smokes: blanketing smokes, which are laid close to the enemy to obscure his vision, and screening smokes, which are laid close to the friendly troops to screen them and the terrain from enemy observation and fire. The ideal smoke agent has the same technical requirements as for the gases, but has the following tactical requirements: (1) high total ob-

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1. Prentiss., op. cit., pp. 35-46.
2. Idem.

scuring power, (2) high persistency, (3) large smoke-producing capacity, (4) high specific weight relative to air, (5) low temperature of generation, and (6) no harmful physiological effect. White phosphorus comes closest to this ideal except that unless used on the progressive burning principle, it is low in persistency; the smoke generated is lighter than air, and being a product of combustion is hotter than the surrounding air and rises even more quickly; the vapors are poisonous, and the burning phosphorus inflicts painful wounds; it has to be stored and loaded under water.[1]

Incendiaries are of the intensive type where the heat and flames are concentrated in a limited space in order to set fire to heavy construction and targets difficult to ignite, or the scatter type, where the incendiary is scattered in a number of small burning masses over a relatively large area in order to initiate fires at a number of points simultaneously in large targets or inflammable or easily ignited materials. The ideal incendiary should have the same technical requirements as those for gases and smokes, and the following tactical requirements: (1) high combustibility, (2) high temperature of combustion, (3) fire not extinguishable in flight, (4) fire unquenchable with water, (5) sustained fire generation, (6) combustion with flames, and (7) should be spontaneously combustible. Phosphorus again comes nearest this ideal, having little or no failings, with only the difficulty in storing and handling as a deterrent.[2]

1. Prentiss, op. cit., pp. 35-46.
2. Idem.

F. Weapons

Most of the chemical agents can be used in the regular projectiles, such as the bullet, hand and rifle grenade shell, and bomb. In many cases, however, special apparatus is necessary.

Smoke pots and candles are manufactured and function in the same manner as the position or ground light, except that the candle is operated manually by grasping the external loop of the ignition device and moving it rapidly back and forth until the match head is ignited.[1]

The Livens projector fires in one salvo a large number of high capacity bombs for a maximum distance of 1800 yards, and the bombs are already in the target area when they burst. The bombs used are quite heavy, however, and a great deal of time is required for the installation of the projector.[2]

The chemical mortar is a valuable weapon, being mobile, very flexible, and adapted for a variety of tactical situations. It is used for gas, smoke, and incendiary shells, and is particularly effective with phosphorus. It is comparatively silent as compared with the Livens projector, and there is no flash, hence the enemy is not warned of the approach of gas by a tell-tale noise or enormous flash.[3]

The cylinder operates by means of gas pressure exerted on

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1. Faber, op. cit., II, p. 235.
2. Hessel, op. cit., pp. 106-7.
3. Ibid., p. 108.

the liquid contents. Liquid carbon dioxide is added, its high vapor pressure building up pressure in the void left above the liquid. This pressure is exerted against the surface of the liquid. When the valve is opened, this pressure forces the liquid downward causing it to seek an outlet through the eduction tube, the valve, and finally the nozzle. The cylinder is used to spray gases, smokes, and incendiaries, but too much time is required for installation and it depends upon the direction of the wind.[1]

The land mine is a container filled with a persistent chemical agent, usually mustard gas. Attached to it externally is a tube holding a small amount of explosive sufficient to open the container and scatter the contents. The mine is exploded by a detonator which is connected up and fired by a blasting machine. It is used chiefly in defensive missions, particularly withdrawals and retirements, the object being to render the terrain unfit for the transportation of troops.[2]

The flame thrower contains three essential parts: (1) a ring-shaped oil container surrounding (2) a spherical vessel containing compressed nitrogen which is used to expel the oil, and (3) a flexible tube of rubber and canvas carrying the jet. The whole apparatus is arranged to be carried on the back.[3]

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1. United States Chemical Warfare Service, Chemical Warfare Service Field Manual, p. 19.
2. Ibid., p. 20
3. Fries and West, op. cit., pp. 349-350.

Airplane sprinkling apparatus consists of two tanks, one containing the chemical agent and the other a propellant gas (like carbon dioxide), and the necessary valves. It is very heavy and must be carried by a bomber at high altitudes and at night when there is little wind. The airplane spraying apparatus uses no ejection pressure. It consists of light streamlined tanks - one fastened to each wing, discharge valves, discharge lines, air vents, and the necessary connections. It must be carried by fast, low-flying planes and operated at very low altitudes. Such apparatuses are used mostly to lay smoke screens.[1]

1. Hessel, op. cit., p. 112.

CHAPTER VI THE SOLDIER

A. Food

The civilian happily settled in an arm chair after a hearty meal, his feet in comfortable slippers, gently toasted by the open fire, takes his comfort very much for granted; he is, indeed, quite irritated if it becomes necessary for him to quit his easy chair for long enough to twirl the dials of the radio in order to get his favorite program. For the soldier on active duty, however, food, adequate clothing, and shelter are matters of serious concern, and comfort for him consists in being dry and warm and having enough to eat and water safe to drink.

Above all, enough to eat, for he can endure muddy trenches and cold feet only so long as he is not hungry. Napoleon is responsible for the maxim "an army walks on its stomach", and the chemists know how much effort and research have been required to perfect the means of feeding a modern army.

In the canning of foods chemists have been constantly improving the metal for the containers and the preserving process. To reduce the weight of canned foods, meats are smoked, beef is boned, vegetables are dehydrated, vinegar is concentrated, fruits are dried, coffee is compressed into soluble cubes - in other words, foods are reduced in bulk while their flavor and caloric value are retained.[1]

But before food can be canned it must be raised. Accordingly, chemists synthesize fertilizers to raise such food, es-

1. Hessel, op. cit., p. 12.

pecially in time of war when the nitrogen so essential for use as a fertilizer is absorbed in the manufacture of munitions.[1]

The chemist has also found a use for cottonseed (linseed) oil. Most shortenings, including the butter-substitute oleomargerine, are made by the hydrogenation of cottonseed oil.. At the same time the cottonseed meal and hulls are fed to cattle.[2]

1. Hessel, op. cit., p. 12.
2. Ibid., p. 13.

B. Equipment

The chemist has done more than save money for the United States. He has made the soldier far more comfortable, first by providing him with water - and - gas proof clothing and second, by the development of aluminum equipment which has greatly reduced the weight of the pack.

Into every item of the soldier's equipment have gone one or more chemical products. Even the composition of the buttons in his uniform has been changed, because it might mean the difference between life and death for their wearer: metal buttons reflecting the sun make excellent targets; the vegetable ivory type now standard on American uniforms are invisible from a distance and are non-inflammable.[1]

The dyes which go into the making of uniforms are also important. Their color may be even more dangerous than flashing buttons, for if the whole man is visible the enemy machine gunner can aim at a vital part. The dyes must produce a fast color, which is also hard to discern on the battlefield and does not show up well on the usual photographic film.[2]

It is the chemist's job to supply shoe leather which is strong and substantial, yet as flexible as is consistent with hard wear, and as light as is compatible with durability. Consequently he is constantly developing ways of improving the processes used in the tanning industry as well as insuring the uniformity of all current operations.[3]

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1. Hessel, op. cit., p. 14.
2. Idem.
3. Ibid., pp. 15-16.

C. Protection Against Chemical Warfare

The gas mask is the most essential item of gas protective equipment for soldiers. The military mask consists of two essential air-purifying elements; one, called the filter, is made of felt and removes exceedingly small solid and liquid particles floating in the air, while the second purifying element contains activated charcoal and soda lime and has the property of removing toxic vapor molecules from the air.[1]

The attraction between activated charcoal and toxic vapor molecules may be likened to that which exists between a magnet and iron filings; the iron filings beingsimilar to the toxic gas molecules, while the charcoal may be likened to the magnet. Ordinary charcoal has no value as a canister filling but ordinary charcoal when treated under the proper conditions with air, carbon dioxide, or steam (singly or in combination) undergoes remarkable changes both in structure and in properties. When these changes have reached their greatest extent the charcoal will adsorb its own weight of poison gases and will hold the molecules securely and prevent their re-evaporation into the air. This phenomenon is called "adsorption",while the process of increasing the adsorptive power of charcoal is called "activation." [2]

Since charcoal does not hold tenaciously certain highly volatile acid gases, notably phosgene, but gradually releases

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1. United States Chemical Warfare Service, The Story of Chemical Warfare, p. 9.
2. West, Clarence J., The Chemical Warfare Service, pp. 156-159.

them to the passing air current, soda lime is added to compensate for this deficiency. After continued exposure to certain gases, such as phosgene, a gradual transfer of the gas to the soda lime takes place, thus leaving the charcoal free to pick up more gas. Soda lime, therefore, reacts chemically with acid gases to supplement and reinforce the action of charcoal.[1]

Gasproof clothing is needed when a person enters an area where vesicants are present. Such clothes are designed in the form of coveralls with hood, or parka, attached. Clothing of this type is made of oiled fabrics, rubberized fabrics or other mustard-proof materials. They are worn over the usual underwear, and acid-proof rubber gloves and rubber boots complete the outfit. Clothing of this type becomes too hot to wear for long in summer weather.[2]

1. Fries and West, op. cit., pp. 255-258.
2. United States Chemical Warfare Service, The Story of Chemical Warfare, p. 10.

D. Disinfectants and Fumigants

The gas mask is the most conspicuous weapon of defense with which the chemist supplies the soldier but it is by no means the only one. Out of test tubes come the drugs which combat disease and the disinfectants which destroy disease germs, and without drugs and disinfectants the soldier's chance of survival would be pretty slim. So efficient are the modern weapons of war that the men who face them would be lost if they were not in good physical condition, and sure to receive effective medication when wounded.

Soldiers in barracks and trenches, sailors on battleships and submarines, must be protected from enemies quite as deadly as any human foe. The germs of communicable diseases thrive where many men are forced to live in close quarters and, unless disinfectants are used freely and intelligently, epidemics will occur. And when sickness does strike a camp or ship, proper fumigation alone will keep it from spreading. That is why chlorine - for water supplies and sanitary equipment - sulfur dioxide and other fumigants are among the most important supplies for the army.

The greatest of these is chlorine, for that same substance which, in gaseous form, is so fatal to men who breathe it, in water solution kills the deadly typhoid germ and thereby saves men's lives. Twenty parts of bleaching powder - whose most active principle is chlorine - per million parts of water is suf-

ficient to kill 90 to 95 percent of all bacteria in water.[1]

Bleaching powder is also used to decontaminate areas immediately after a gas attack, reacting with mustard gas to form a non-vesicant compound. Other decontaminating compounds are sodium sulfide, dilute sodium hydroxide, sodium carbonate, and a solution of sodium bicarbonate in sodium hypochlorite.[2]

1. Hessel, op. cit., pp. 20-21.
2. Prentiss, op. cit., pp. 574-5, 580-2.

E. Serums and Medicines

Disinfectants and fumigants are the first line of defense against disease; serums and other preventative substances come next. Every veteran of the last war remembers the series of "shots" which were his introduction to army discipline, and he should remember them with gratitude. Thanks to the biochemists and bacteriologists who developed these serums, only a small percentage of men died from typhus or cholera - scourges which a few generations ago took a tremendous toll of life.

Research chemists are working all the time to give the soldier immunity from disease, medicines that will cure the maladies that strike them, and antiseptics that will heal their wounds.

Acetylsalicylic acid - commonly known as aspirin - is one of the drugs that was used in tremendous quantities during the "flu" epidemic. Dakin's solution - a solution of hypochlorous acid containing the active principle chlorine - protects against tetanus bacilli and streptococci fecali present in the soil of the trenches. Sulfanilamide has been found useful in the treatment of infections caused by hemolytic streptococcus, gangrene (the nightmare of the wounded soldier), meningitis, gonococcus, and certain types of pneumonia. Sulfapyridine, a related compound, has shown great promise in the treatment of all types of pneumonia. The vitamins are invaluable in keeping the soldier fit and strong.[1]

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1. Hessel, op. cit., pp. 23-25.

An oxygen tent gives relief to soldiers affected by lung injurants. Kerosene or rubbing alcohol is used to wash the area of the body affectedby vesicants, while a solution of sodium bicarbonate, sodium chloride, and water soothes the eyes irritated by mustard gas. A protective ointment against mustard gas consists of zinc oxide, linseed oil, and lanolin. The vapors of a solution of chloroform, ether, and ethyl alcohol will counteract any sternutatory effects, and victims of lacrimators are treated with a salt and boric acid eye-wash. Liquid acid smoke is washed off the skin with water, and the affected area covered with baking powder or a solution of any mild alkali. Burns from phosphorus are sprinkled freely with a weak solution of copper sulfate, the copper coated phosphorus particles removed by washing or with a forceps, and the resultant burn treated with tannic acid or some other standard treatment.[1]

1. United States Chemical Warfare Service, Medical Division, First Aid Treatment for Injuries from Chemical Agents, pp. 1,6-7, 11-13; United States Surgeon General's Office, Medical Aspects of Gas Warfare, p. 77; Fries and West, op. cit., pp. 276-7.

CHAPTER VII THE ARMAMENTS

Every gun, battleship , submarine, tank, and airplane has steel in some if not in every part of its construction, and the same is true of bombs, shrapnel, and shell. Even the soldiers' helmets are made of steel. This does not mean thatall armaments are made of the same material. Quite the contrary: into each of these instruments of war there has gone a different variety of steel, a different alloy, especially suited to the purpose for which it is used - an alloy which has been "planned that way" by chemists.

The science of metallurgy leans very heavily on chemistry. All the essential metals - nickel, copper, chromium, zinc, lead, iron, etc., are found in combined form in the earth's crust, and their isolation and identification are accomplished by chemical processes. Then, purified by chemical methods, they are tested by chemists to determine their properties and characteristics, and combined to form the numerous useful alloys which are the basis of modern armament construction.

A. The Battleship and the Submarine

The battleship is characterized by its armor plating which serves as a bulwark against enemy shell, and with each improvement in the effectiveness of projectiles the metallurgist has been forced to devise some means for increasing the toughness of the armor plating. The best armor plating today is made from Krupp steel. By adding chromium to nickel steel and "cementing" it by passing illuminating gas white hot across the face of the heated plate and then still further hardening one face by very hot and quick heat while the other side is kept cool to increase toughness, the Krupp works produces a steel harder than glass which has been adopted in all armor manufacturing and which is standard the world over. Carbon is the principle hardening element, nickel gives it toughness, and chromium adds hardening without extreme brittleness.[1]

A variety of chemically-treated paints are necessary. There are anti-fouling paints which act both as a paint and germicide, insecticide, and fungicide by killing marine growths; paints which protect the metal of the ships and their guns against the corrosion from sea water; spar varnishes; and paints which protect marine pilings from borers.[2]

The chemist also plays an important part in the manufacture of the following products used in ships: (1) synthetic rubber,

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1. Hessel, op. cit., pp. 59-60.
2. Morrison, A. Cressy, Man in A Chemical World, pp. 130-131.

(2) dyes, (3) cleansing compounds, (4) refrigerants, (5)films, (6) steel, (7) glass, (8) oils and fuels, (9) explosives, (10) smokes, and (11) flares.[1]

The submarine consists of a steel shell with deck equipment of chromium nickel steel. In addition to the products used in battleships the submarine requires (1) insulating materials for protection against dampness andmoisture, (2) heating equipment, (3) canned and preserved foods, (4) fireless cookers, (5) hot water reservoirs, (6) Diesel engines, (7) storage batteries.[2]

To aid the raising of men from a sunken submarine a simple device called the "lung" is used which enables a man to breathe under water for a period. It resembles a gas mask in appearance, the main difference being that for the user of the "lung" the surrounding atmosphere is a liquid instead of a gas. In addition there is a small oxygen cylinder which supplies fresh oxygen to replace that used up in breathing, so that the wearer can rely on it for about one and one-half hours.[3]

1. Hessel, op. cit., p. 58.
2. Hoar, Allen, The Submarine Torpedo Boat, pp. 84,112,126.
3. Ellsberg, Edward, Men Under the Sea, pp. 89-90.

B. The Motor Vehicle and the Tank

The automobile - from tail-light to bumper - is a product of chemical industry, since so many of the materials of which it is made are produced by processes of chemical change of nature's raw materials.

The frame, body, and fenders are made of carbon steel which is strong, tough and easy to form. The rear hubs, front axle, steering knuckles and leaf spring are made of alloy steel. Steel plus proper amounts of silicon, manganese, chromium, and vanadium yields practically unbreakable springs.[1]

In the engine cast iron alloyed with chromium and nickel makes up the cylinder block and head which is more easily machinable and more resistant to heat expansion and to wear. The spark plugs have tungsten contact points in the distributor and nickel-barium wire at the points. The bearings are made of copper-tin bronzes or alloys containing cadmium, calcium, and even silver. The exhaust valves are made of silchrome - a steel alloyed with silicon and chromium; in trucks the valves and their seats are being faced with a well-known alloy of chromium, cobalt, and tungsten. Pistons are often made of alloys of aluminum or magnesium, which combine strength with light weight, thus requiring less power for their starting and stopping in the up and down strokes in the cylinders.[2]

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1. Morrison, op. cit., pp. 103, 122.
2. Ibid., pp. 122-3.

The electric storage battery, upon which the successful operation of the engine depends, is essentially a series of chemicallyproduced lead plates, hardened and stiffened with antimony, coated with oxides of lead and suspended in a solution of chemically pure sulfuric acid contained in a chemically produced resinous box.[1]

Tools for the machinery of steel are made of forged steels highly alloyed with chromium, tungsten, vanadium, and cobalt. Tools for the cutting of steel or cast iron are cast from an alloy of chromium, cobalt, and tungsten. In making tools for the working of metals tungsten, molybdenum, chromium, cobalt, and titanium are among the alloying ingredients which allow the tools to cut faster and at higher temperatures without losing their temper.[2]

The use of chemistry is also involved in the manufacture of the following products: (1) rubber tires and synthetic rubber, (2) safety glass, (3) chrome furnishings and handles, (4) plastics and synthetic resins - on the dash-board, steering wheel, etc.), (5) fuel and oil, (6) anti-freezes, (7) no-knock mixtures, (8) paint and lacquer/coating, (9) upholstery, which was originally leather but now artificial leather.[3]

The tank is merely a vehicle with armor plating. When equi-

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1. Morrison, op. cit., pp. 127.
2. Ibid., pp. 103, 124.
3. Ibid., p. 103.

pped with flame throwers it has the task of levelling everything behind the lines and it goes about it by setting fire to every thir d building and letting the resulting fire spread to all the others. It is light and fast, and can dart quickly from place to place. It is manned by crews swathed in asbestos suits who drive their death-dealing vehicle right up to buildings and set them afire by squirtingblazing gasoline inside. A similar technique is used in quieting pill-box forts. The tank blasts its way up to them with the machine guns and a 37 millimeter cannon that it carries, and then shoots flames inside that often burn the defenders to a crisp in a very few minutes.[1]

1. The American Weekly, The Worst Weapon Used in Warfare, p. 2.

C. The Airplane and the Balloon

The airplane in use today represents an important contribution by the chemist to modern warfare because it is almost entirely constructed of chemical products, principally the light alloys. The alloy development has made possible the all-metal plane, which is safer, surer, and faster than its wooden predecessors.

Aluminum castings and alloys used in place of steel parts have brought about a reduction of weight and consequent increase in speed and cruising range. Combined with other metals (copper, magnesium, manganese) aluminum gives a material of great tensile strength and very light weight called duraluminum which is used in the construction of every plane today. Cockpits are enclosed in heat-treated aluminum alloy, oil tanks are of welded aluminum alloy, and all oil lines are of aluminum alloy tubing.[1]

Exhaust pipe is welded from heat-resistant high chrome sheet metal. Landing gear sheer trusses are of chrome molybdenum steel, and in sea planes the pontoons are of chrome-nickel steel sheets stabilized with columbium. To reduce oxidation and warping the valves are made from an alloy of iron, silicon, and chromium. The engine has been improved by the use of alloy steels, and carbon steel nuts and nickel steel bolts are used in all planes.[2]

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1. Hessel, op. cit., p. 66.
2. Ibid., pp. 66-67.

Rubber is now used as an outer covering for the gas tanks. If the tank is penetrated by a bullet, the leaking gasoline causes the rubber to swell, thus plugging up the hole swiftly. Chemically produced unbreakable glass, synthetic rubber for tubing, plastic instrument cases and trims, luminous dials - of radium or zinc sulfide, paint, and cement are integral parts of the plane.[1]

"Dope" - the substance used to treat the cloth covering of the wings, to make it shrink and become perfectly taut - is also a chemical product. At first cellulose nitrate was used, but it was inflammable and caused the cloth to deteriorate. The chemists then developed cellulose acetate (now the basis of celanese) which has neither of these two detrimental qualities. Because it does not cause shrinking as good as the former, the wings are given two coats of cellulose acetate followed by three of the nitrate and, since both are injured by sunlight, a final coat of spar varnish to which a pigment is added to cut out the injurious light rays.[2]

Much chemical research has gone into the production of suitable dyes and filters for aerial photography. Ordinary photographic emulsions are not sensitive to all colors, so certain dyes are added and filters (transparent color media) used to insure correct color reproduction, eliminate the effect of

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1. Hessel, op. cit., P. 68
2. Idem.

haze, and secure sufficient contrast so that ground objects may be easily identified in the photograph.[1]

Chemists have increased the petroleum reserves and the gasoline output by means of the cracking process, which breaks up the heavy molecules of the higher boiling constituents of crude oil into smaller molecules similar to those in gasoline by applying heat under the proper conditions of pressure. Oil in the refinery is subjected to very high temperature and pressure - a condition met only by the use of modern steel alloys - with a resultant yield of 50 to 60 gallons of gasoline from 100 gallons of crude oil, as compared with 20 to 25 gallons of gas formerly.[2]

Not only does the cracking produce more gasoline, but this gasoline possesses a high anti-knock value. Most anti-knock fuel contains ethylene dibromide, tetra-ethyl lead, and some dye. Anti-freeze mixtures most widely used are denatured alcohol, glycerine, synthetic methanol, andethylene glycol. These materials have increased the efficiency of the plane and made possible the use of tanks and other motor vehicles in most winter weather.[3]

Proper lubricants are also necessary. American mineral oil, which was introduced about 1880, has made possible the development of modern engines and machines.[4]

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1. Hessel, op. cit., p. 71
2. Ibid., pp. 74-75.
3. Ibid., pp. 75-76.
4. Ibid., p. 77.

Balloons were formerly lifted by hydrogen - the lightest of all gases - which was generated in the field by ferrosilicon and caustic soda. Because hydrogen is inflammable and air diffuses with the hydrogen in the balloon to make an explosive mixture, it has been replaced by helium, which is non-flammable and has 92 percent the lifting value of hydrogen.[1]

Chemistry is necessary to develop a suitable cloth for non-rigid observation balloons. The pores of a finely woven cotton cloth are filled with viscose, a substance which does not weaken the fabric, and two or three plies of such long-fiber cotton cloth are cemented together with rubber cement and then vulcanized.[2]

1. Seibel, C.W., The Chemist's Contributions to Aviation, pp.17, 30-31.
2. Ibid., pp. 19-21.

CHAPTER VIII THE RELATION OF CHEMICAL INDUSTRY TO CHEMICAL WARFARE

There has always been a close connection between the science of chemistry and the art of war. Experiments undertaken for purely scientific or peaceful purposes often lead to inventions of military importance and vice-versa.

Chemicals can be used for peace or war. Often the processes by which peace products or potent war materials are made differ only in the degree of purification and preparation. The natural raw materials from which both peace and war products are made and which so much resemble Dr. Jekyll and Mr. Hyde are found in large quantities in the United States: salt, water, grain, sulfur, air, limestone, cellulose, petroleum, and coal. From these natural materials are made the heavy chemicals: sodium hydroxide, chlorine and hydrochloric acid (from salt), alcohol, acetic acid, and acetone (from the fermentation of grain), ammonia and nitric acid (from air), sulfuric acid (from sulfur), and coal-tar derivatives (from coal). With petroleum and cellulose these heavy chemicals constitute the basis of all industrial activity. One or more of them appears in some capacity in the production of practically every man-made object.[1]

The following is a discussion of certain chemicals whose uses can be applied to war or peace. In more than one instance

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1. Hessel, op. cit., p. 123.

the processes and equipment for making military products are practically identical, making it possible for certain plants to be changed almost overnight into munitions or war gas factories.

Sodium hydroxide-commonly called caustic soda - is prepared by electrolyzing salt and then hydrolyzing the sodium which collects at the cathode. It is used in the glass industry, in the production of soap, and in the manufacture of films, rayon, and other textiles. It figures at one time or another in the preparation of practically every explosive and of nearly all the combat gases.[1]

Chlorine is also prepared by the electrolysis of salt, and may be collected as a gas or treated with hydrogen to form hydrogen chloride which is dissolved in water, giving hydrochloric acid. With hydrated lime it is used as a bleaching agent by laundries and pulp and paper industries, and as a disinfectant at home. It is also used in making dyes, in mining gold, and in water purification. With carbon it gives chloroform and cleaning fluids. It can be used as a toxic gas alone or combined. In the form of hypochlorite it sterilizes infected wounds.[2]

Many of the war gases, especially those containing chlorine, have valuable peacetime uses. Chlorpicrin, cyanogen chloride, and cyanogen bromide are well adapted to killing the boll weevil and other similar insect-destroyers of grain. The lacrimator chloracetophenone and the sternutator diphenylamine - chlorar-

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1. Hessel, op. cit., P. 127.
2. Idem.

sine are excellent for use in bank vaults, safes, etc. Phosgene is an important intermediate in the making of certain dyes, medicinals, perfumes, and flavoring agents. Hydrocyanic acid today is the greatest destroyer of insect pests in orange and lemon groves of California and the South, and is being considered for use by trappers to kill wild animals.[1]

Alcohol is obtained by the fermentation of grain and is used chiefly as a commercial solvent. It is necessary in making films and lacquers, and in compounding medicines. With aniline it gives a compound which is an intermediate in the making of dyes. At the same time it is used in the manufacture of mercury fulminate and mustard gas.[2]

Ethylene gas may be prepared by passing alcohol vapor through kaolin fragments at a high temperature or by the "cracking" of petroleum. With chlorine it gives a solvent which is used to extract certain vegetable oils from their seeds, and with bromine and tetraethyl lead it produces a standard anti-knock mixture. Alone, it gives oranges their beautiful and uniform color. With hypochlorous acid and sodium hydroxide, it forms ethylene glycol which is an anti-freeze for gasoline or nitroglycerin and dynamite. Ethylene is also a starting point in the manufacture of mustard gas.[3]

Acetic acid is prepared by the fermentation of alcohol or by the destructive distillation of wood. When diluted it be-

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1. Fries and West, op. cit., pp. 427-430.
2. Hessel, op. cit., p. 124.
3. Idem.

comes vinegar. It is used in lacquer solvents, in the manufacture of pigments (white lead and verdigris), in the printing and dyeing of textiles, in the manufacture of celanese (made by the action of acetic anhydride and cellulose), and in the manufacture of non-inflammable films. As cellulose acetate it is used to make "dope".[1]

Acetone is obtained by the fermentation of grain and by passing acetic acid vapors over red hot lime, which acts as a catalyst. It is a valuable process solvent in the production of nitrocellulose, guncotton, fats, resins, rayon, artificial leather, photographic films, pyroxylin, plastics, lacquers, and paint and varnish removers. Nail lacquer removers are usually composed principally of acetone.[2]

Sulfuric acid is prepared from sulfur and is used extensively in the fertilizer, oil refining, and iron and steel industries. Together with nitric acid it converts cellulose into guncotton.[3]

Ammonia and nitric acid can be prepared from the nitrogen in the air. Ammonia is used in petroleum refining and in the manufacture of explosives. Nitric acid is used in the fertilizer industry and is important in the manufacture of dyes, films, artificial leather, lacquers, and many other products. It is a basic substance in the manufacture of explosives, because practically all modern explosives are mixtures of nitrated organic compounds which require the use of both nitric and sul-

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1. Hessel, op. cit., p. 124.
2. Ibid., p. 125.
3. Ibid., p. 126.

furic acids in their manufacture. It is interesting to note that basically there is no difference between the commonly used lacquers, nitro-cellulose films, and guncotton. All are produced by the action of nitric acid, in the presence of sulfuric acid, on cellulose either in the form of cotton linters or wood pulp. The only difference resides in the length and strength of the treatment and in the purification afterwards.[1]

Limestone, or calcium carbonate, is used in the pulp and paper industry and in the making of bleaching powder, glass, and ceramics. It is also an essential component in the product of the synthetic rubber, neoprene, which is expensive but better than ordinary rubber in that it is more resistant to the action of oil and gasoline. Limestone, chlorine, and picric acid together yield the war gas chlorpicrin.[2]

Cellulose is present in cotton and in wood pulp. Cotton is almost pure cellulose while wood pulp also contains large amounts of lignin. Cellulose is the raw material for cloth, rayon, photographic and movie films, and cellophane. Cotton linters are used to make artificial leather, and cottonseed oil may be refined for use in salads or cooking, or split into its constituents glycerine and organic (fatty) acids. The organic acids are combined with caustic soda or soda ash to make soap, while glycerine is used in medicines or in the making of nitroglycerine. Cellulose is also converted to guncotton by the action of nitric and sulfuric acids.[3]

1. Hessel, op. cit., p. 125.
2. Ibid., pp. 127-128.
3. Ibid., p. 126.

Petroleum is used in the manufacture of a cheap but good synthetic rubber. The "cracking" of petroleum yields more gasoline as well as high - octane (Anti-knock) fuel. Gases derived from petroleum can produce glycerine, and also the nitroparaffins which are not only powerful and inexpensive explosives but are suitable as solvents for nitrocellulose lacquers and a wide range of natural and synthetic resins.[1]

The coal-tar chemicals are the most important chemical products which enter into the question of national defense. Coal-tar is obtained as a by-product in the manufacture of coke in by-product ovens and in the manufacture of coal gas for city distribution. In both of these processes, the essential chemical operation is to decompose certain special grades of bituminous coal by heating to high temperature out of contact with air. The products obtained are coke, tar, light oils, ammonia, and gas.[2]

The following substances, isolated from the light oils and tar, are of commercial importance: benzene, toluene, xylene, cymene, naphthalene, methylnaphthalene, anthracene, methylanthracene, phenanthrene, carbon bisulfide, carbazol, phenol, cresol, xylenol, pyridine, quinolin, and free carbon. They are used extensively as intermediates in the manufacture of dyes, medicinals, explosives, and war gases. Complex mixtures made from coal-tar by fractional distillation appear in commerce

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1. Hessel, op. cit., p. 189.
2. Prentiss, op. cit., p. 634

under the names of naphtha, light oil, dead oil, creosote oil, anthracene oil, and pitch of various grades.[1]

So, starting with a few raw materials it is possible to produce a vast number of varied chemical products, some of which may be prepared simply, by mixing a number of chemicals in a container, while others require complicated processes and a large amount of equipment. In the synthesis of the coal-tar intermediates and finished products, however, there is a great similarity in the types of equipment required for the preparation of widely different products. Also there are certain types of chemical reactions which are constantly being repeated in the building up of the different compounds. Such reactions include: (1) nitration, (2) nitrosation, (3) halogenation, (4) sulfonation, (5) reduction, (6) oxidation, (7) fusion with alkali, (8) hydrolysis.[2]

It is evident that those who have a thorough knowledge of these reactions and can successfully carry them out on a commercial scale can, in peacetime, produce commercial chemical products and, in wartime, produce war gases and explosives. It is for this reason that the chemical industry is of such great importance in the matter of national defense.

1. Prentiss., op. cit., p. 634.
2. Ibid., p. 636.

CHAPTER IX SUGGESTIONS TO THE TEACHER

The teacher of chemistry realizes that this is an age of science, and that the leader among sciences is probably chemistry. Practically all big industry is chemically controlled and when we look at the war in Europe with its nightly bombing raids, we realize more and more that the chemists of England are fighting for their lives and the lives of their people against the chemists of Germany.

But the question of the teacher is: "How can I connect a high explosive such as TNT, having the complicated chemical formula of $CH_3C_6H_2(NO_2)_3$, with the ordinary beginning student in Chemistry? Probably I should wait until the student has been into chemistry for awhile, before attempting to use the chemistry of warfare as motivation."

That may be wise and can be done, yet an explosion is only a rapid decomposition of a solid into gases and the first experiment in the laboratory is likely to be just that. In a high school chemistry course the first two subjects usually taken up are the definition of a chemical change, and the study of the gas oxygen. Consequently, to illustrate a chemical change and, at the same time, to show a method of obtaining oxygen, a solid, such as red mercuric oxide, is heated in the laboratory, and a chemical change gradually occurs whereby a gas which has a much greater volume tha n the original substance is obtained (oxygen), together with a residue of a silver-like liquid (mercury).

But if that oxygen had been freed quite rapidly, we would have had an explosion, or power sufficient to propel a bullet or small projectile perhaps. It is obvious that the elements such as oxygen, hydrogen, carbon, and nitrogen are likely to have a part to play in explosives, one important phase of war.[1]

Thus we begin to build up a connection from the beginning of our course in chemistry, if we wish. A longer story here by an informed teacher brightens the interest. Probably, however, it is best to discourage mastery or even understanding and to tell the pupils not to worry. If any are interested there are readings at hand. The matter comes up again: soon some pupil wants to read on chemistry in warfare, and the teacher guides him into a reading on which he can make a report to the class, after a week or two. The interest spreads. The teacher receives other requests for references.

By this time the preliminary work in chemistry has made some progress. Probably water, designated by H_2O, has been separated into its two component gases, hydrogen and oxygen. The pupils marvelled that the volume of hydrogen evolved was double that of oxygen. The teacher has had the pupils note also the large volume expansion as water turns to gases. One cubic centimeter of water is transformed into almost 2,000 times the volume of gases, i.e., the ratio is 1 to 2,000. Had these gases been released quickly we would have had the basis for an explosion.

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1. McPherson, W., Henderson, W.E., and Fowler, G.W., Chemistry for Today, pp. 21, 33-4.

Apparently the quest for an explosive is merely a try-out to find a substance that decomposes into gases, releases such gases quickly, leaves little or no residue, and is easily controlled. By control we mean that the substance doesn't explode when we don't want it to, yet can be exploded or detonated easily when we do want it to explode; provided, of course, that the explosion is not too violent if used in a gun barrel, and if used in a bomb probably the more violent the better. Now that is exactly the process by which "bigger and better" explosives have been found. Sometimes it has been centuries between steps. For example, picric acid was discovered by Glauber in 1650 and used for many years as a yellow dye, but it was not known to be explosive before 1805, and then not put to practical use until 1871 when Sprengel discovered that it could be detonated with a fulminate of mercury cap.[1]

When further progress in the chemistry course has been made and we come to the study of nitrogen, we see how most explosives contain nitrogen because it serves to hold the oxygen loosely, thus facilitating the ease of decomposition of the explosive; how nitrogen is so necessary for fertilizer as well; how certain legumes collect and fix nitrogen in the soil; how Chile saltpeter was the chief source of nitrates so necessary for fertilizer and explosives, and when Germany was blockaded during the World War and could not obtain the nitrates, her great scientist,

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1. See chap. III, sec. A.

Haber, discovered how to take nitrogen from the air on a commercial basis.[1]

Still further on we learn how the products from coal tar yield substances which are vital both to industry and warfare. From this sticky tarry mass obtained as a by-product in the manufacture of coke (the process consisting of the heating of soft coal in the absence of air), thousands of useful products - dyes, medicines, disinfectants, explosives - are obtained.[2]

The chemistry of the chemical agents is likewise too complicated to plunge into at the beginning of the course, but a little later when the halogens or the metals are taken up the students might be interested in the toxic effects of the various agents, the elements responsible for the physiological action, the peace-time values of the agents, and the effect which such physical factors as boiling point, rate of diffusion, rate of volatilization, and density, have on the dispersal of the chemical agents.[3]

Demonstrations also can be utilized by the teacher. Flame tests illustrate the use pyrotechnics makes of chemistry to obtain the various color effects. The action of smokes and incendiaries in a small way could be also shown by demonstrations. The action of an ordinary firecracker is an excellent example of the detonation of an explosive mixture by means of a fuse. After

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1. McPherson, Henderson, and Fowler, op. cit., pp. 224, 248.
2. See chap. VIII.
3. See chap. V.

such demonstrations, those students who are mechanically minded possibly might like to know more about the structure and operation of projectiles, fuses, and pyrotechnics.[1]

The thesis also furnishes the teacher of a college preparatory class with tangible material for the motivation, explanation, and instruction of many of the basic principles of chemistry. The action of explosives and incendiaries, for example, help explain oxidation, reduction, and the states of matter; the war gases incidentally illustrate the gas laws, and the smokes, colloids; the alloys involve not only the use of the periodic table and the atomic weights of the elements, but lead to a study of the properties of the metals as well; and the reports will involve the use of equations, calculations, and valence. Probably with such vital motivation as here provided, the pupils could easily be led to make special preparation for "exams", using spare time for two or three weeks immediately preceding the examinations.

It is not at all necessary that every member of the class become interested enough in the chemistry of warfare to read extensively, or at all, in this field. The teacher will show other equally interesting opportunities for reading and report, such as (1) indigo and other dyes from coal tar, (2) lacquers that run an auto through the paint shop in three days instead of three weeks, (3) cosmetics; (4) paints, (5) plastics, (6) the

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1. See chap. III, secs. B, C; chap. IV.

vitamins, (7) sulfanilamide and sulfapyridine - the nemesis of infectious diseases, (8) rayon from cotton and wood pulp, (9) nylon hose, (10) photography, (11) soaps from fats and lye, (12) shortenings from cottonseed oil, (13) the tanning of leather, (14) the canning and preserving of food. While some of these products involve chemistry that may be turned to account in warfare, that is an incidental point which may or may not be noted. The point is that chemistry is broad enough to find contacts with some interests of almost any pupil. With the proper guidance he may follow his interests into profitable fields of study in chemistry. At the high school level the procedure will be according to the appreciation technique. It will build up permanent interests and increase the possibilities of further pursuit of chemistry as the pupil studies at higher levels.

Thus the pupil enters into the real romance of modern chemistry. He begins to see its significance and possibilities, and is no longer confined to a textbook that is to be committed, or to the directions in a laboratory manual. The chemistry of warfare has served as a splendid appreciation unit, highly motivating and modifying the regular class work. A few pupils may go far into the chemistry of warfare; other groups of pupils will take up other equally interesting and equally profitable units.

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